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STATE-OF-THE-ART: SWINE WASTE PRODUCTION
AND PRETREATMENT PROCESSES

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ABSTRACT

A review of waste generation and pretreatment processes was compiled, expanded, and interpreted for the swine production industry. The study goal was to unify and refine various experimental and demonstration data into the format of unit processes within an overall waste management system. Typical swine units based upon waste management techniques were detailed as concrete slab facilities, slotted floor-pit units, and swine drylot or pasture operations. The waste yield from all concrete slab or pit units was similar enough to be considered non-differentiated, and thus, were used to define the generated or swine production unit load. This approach was used instead of actual or theoretical raw waste defecation data because the defecated waste load has not been documented for producer facilities. Drylot and pasture unit waste load was estimated at only 0.7 percent-10 percent of the concrete slab or slotted floor-pit production unit waste load.

Pretreatment processes for the production unit waste load were evaluated in relation to land as the terminal receiver and for waste conversion mechanisms affecting utilization processes. The pretreatment effects on waste constituents were examined for all forms of nitrogen, cations or salts, organics, microbial or pathogen content, and nuisance factors. Specific processes investigated which focus primarily on nitrogen reduction were anaerobic lagoons, mechanical surface aeration of lagoons, naturally facultative lagoons, rainfall-runoff retention ponds, oxidation ditch, and overland flow. Those processes documented for utilization were high rate digestion for methane production, solids separation, pyrolysis, refeeding, and composting. Sufficient data or approximations were available to rank these pretreatments with respect to nitrogen removal or conservation and partially to rank according to salt removal or reduction.

The state-of-the-art report confirmed the large number of definitive studies on various pretreatment processes and the characterization of swine waste while certain information gaps were emphasized to direct future work. The need to augment the current technical base with economic analyses of field systems was the principal recommendation. While the report focused on swine wastes, many of the pretreatment process mechanisms and performance characteristics would be applicable to other livestock wastes, emphasizing the inherent similarities of animal wastes.

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SECTION I

CONCLUSIONS

I. SWINE PRODUCTION CATEGORIES AND TRENDS

1. The percentage of swine produced in the three general types of units was 30 percent concrete slab, 20 percent slotted floor, and 50 percent drylot or pasture. The production trends were toward slotted floor and drylot units depending on the availability of investment capital or labor and land.
2. In general, swine production units where manure is exposed to rainfall are not sufficiently documented to allow reasonable estimation of costs to comply with environmental statutes.

II. SWINE PRODUCTION UNIT WASTE GENERATION

1. Within the available literature data for field units no substantial difference was found between the amount of waste constituents leaving concrete slab or slotted floor-pit units.
2. The largest waste generation variations were in volume due to the many different levels of water use. Higher water usage represents greater waste handling and transport costs.
3. Waste loads from drylots or pasture units was not documented in any studies despite the large number (50 percent of all hogs produced) of these facilities. Estimates of the waste load were deduced from climatic and beef feedlot data to be between 2.5 percent and 10 percent and between 0.7 percent and 2.5 percent of the raw waste from concrete slab or pit units for drylots and pasture units, respectively.

III. PRETREATMENT PROCESSES

1. Pretreatment strategy and processes are evolving into 1) those units for improved removal or reduction of nitrogen or 2) those units designed to obtain utilization benefits from swine waste.
2. For maximum nitrogen removal, lightly loaded lagoons and runoff retention ponds yield less than 10 percent of the production unit nitrogen load.
3. For nitrogen conservation, high rate methane generators and composting allow use of the organic fraction and still retain over 70 percent of the production unit nitrogen load. Heavily loaded or small surface lagoons offer waste handling flexibility and also conserve over 70 percent of the input nitrogen.
4. Salt content, although rarely reported in the literature, was removed most efficiently by systems involving soil contact such as overland flow, barriered landscape renovation system, or swine drylot production units. Most pretreatment processes had little effect on the salt or cation content of swine waste.

SECTION II

RECOMMENDATIONS

1. More data are needed on salt content of swine waste and the pretreatment effect of various unit processes on salt content.
2. Management and geoclimatic effects on waste load from swine drylot or pasture facilities should be evaluated to allow better design and economic compliance with environmental regulations.
3. The economic evaluation of existing field scale or producer units must be accelerated to approach the available technical information on swine waste and pretreatment processes.
4. The procurement of economic data for pretreatment process and total system performance will allow better overall design or recommendation of waste management facilities for individual producer situations.

SECTION III

INTRODUCTION

SWINE WASTE MANAGEMENT

The swine production operations are a subclass of the animal production industry and share a number of common attributes with both animal units and manufacturing industries. The principal commonality among industries is in the environmental flow chart which exists for all production operations that convert natural resources into products. This flow chart, Figure 1, represents the fact that less than 100 percent of process input is converted to usable product; therefore, effluents result, which may be treated or partially utilized, prior to reaching a terminal receiver.

The exact combination of production unit, pretreatment process and terminal receiver should result in the minimum total system cost per unit of production within the constraints of regulations and producer objectives. Thus, the engineer or agricultural specialist must have available the performance of system components and the methodology for combining the elements into a total system. This design methodology for overall waste management follows a general stepwise pattern characteristic of most industries. The individual swine pretreatment processes are becoming well documented in research and extension literature.

The waste management system design begins with consideration of the various alternative terminal receivers, e.g. the plant-soil system, receiving streams, etc. The first step is to establish allowable receiver rate, mass of waste per unit of receiver per unit time which is environmentally acceptable for the specific area. This rate is determined for constituents or families of compounds present in the waste, e.g. nitrogen, salts, organics, etc. The quotient of the waste generation per unit of production and the receiver acceptance rate yields the receiver size needed per unit of production. A given receiver size represents a cost, e.g. land purchase, distribution system, pumping costs, etc. The selection of the most cost effective total waste management system involves the iterative consideration

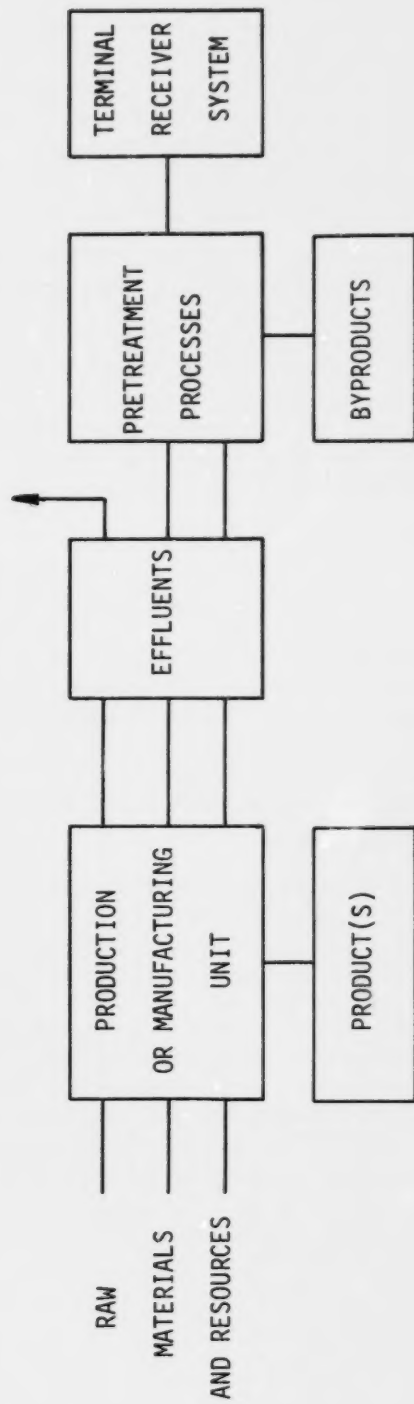


Figure 1. Environmental flow sheet for production process.

of the ultimate receiver and the available pretreatments. If only the waste generation and terminal receiver are involved, the resulting system is a zeroth order pretreatment with only waste handling effects, Figure 2. Next, a pretreatment process is selected to reduce the size and cost of the terminal receiver, Figure 2. The pretreatment process removes, converts to usable or nonpolluting form, or separates the limiting constituent(s) for a cost expressed per unit of material treated. If the process selected is beneficial, the new combination, Figure 2, will have a lower total system cost.

The methodology of balancing waste generation and pretreatment against the terminal receiver is iterated by adding more pretreatment processes or exchanging one process for another, Figure 2. At a certain level of pretreatment, the cost savings associated with reducing the terminal receiver size are not greater than the increased pretreatment costs. The total system cost is thus minimized. Approached in this sequential pattern and based on utilizing the maximum capabilities of the terminal receiver, a wide variety of terminal receivers and pretreatment process can be compared on a uniform basis.

SWINE PRODUCTION INDUSTRY

Receiver Categories

In a similar fashion to Figure 2, the production of feeder pigs, breeding stock, or slaughter hogs can be represented as having a waste generation that is amendable to several pretreatment processes and requiring a terminal receiver, Figure 3. Consideration of possible terminal receivers indicates that there are three possibilities: 1) water-based systems, 2) engineered recycle or byproduct recovery systems, and 3) land-based systems.

Results for research and demonstration scale stream discharge systems (Hermanson 1967, McKinney 1967, Laak 1974) using a variety of primarily aerobic pathways for pretreatment have documented that costs of such processes are prohibitive and expected results questionable. It should be noted, however, that overseas, primarily in centrally planned nations, aerobic treatment with stream discharge is widely practiced. Therefore, under some conditions of size, existing land, and other constraints, pretreatment and water-based discharge may be feasible. For the regulatory objectives and producer flexibility characteristic of the United States, aerobic pretreatment to allow stream discharge is not acceptable; hence, further discussion is omitted here.

DESIGN OF PRETREATMENT PROCESS-TERMINAL RECEIVER

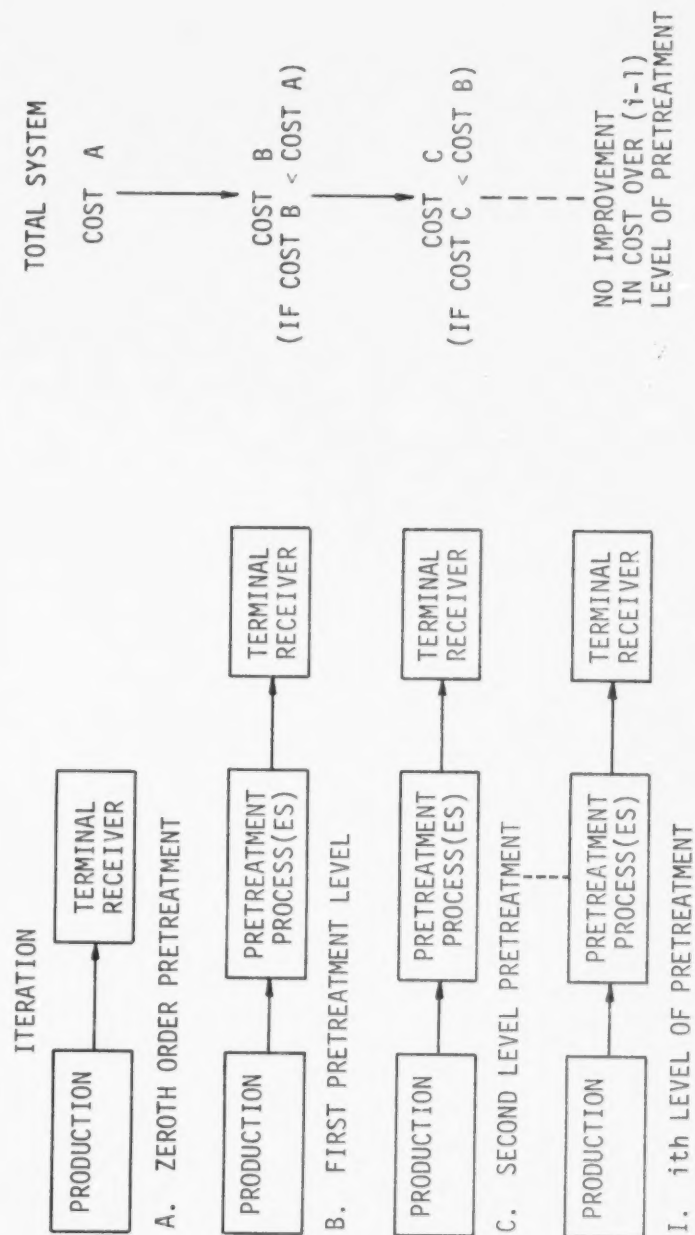


Figure 2. Design stages to select the least cost balance between level of pretreatment for limiting constituent(s) and magnitude of terminal receiver.

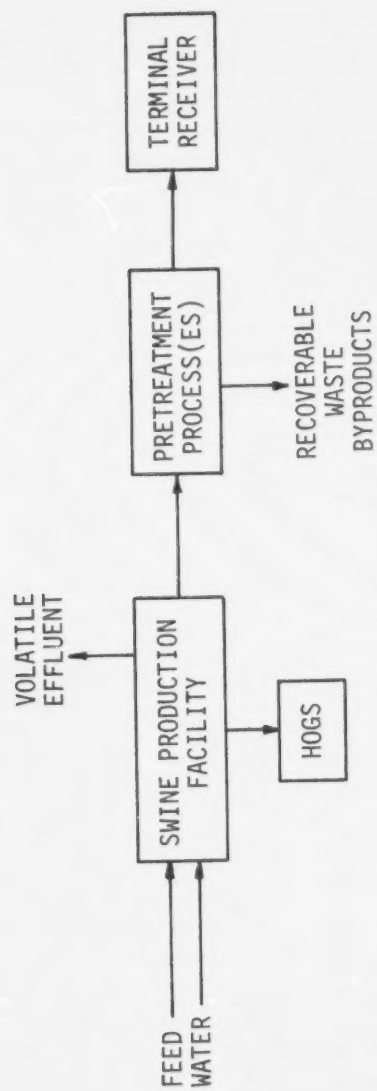


Figure 3. Total environmental schematic of swine production system.

Engineered recycle or byproduct recovery systems are categorized separately if the end result is a very high percentage of the waste input. The resulting recycling process effluent is small so that disposal of this fraction is not a critical factor. In this category of terminal receiver are such processes as pyrolysis and composting.

The third receiver system is land-based and entails a variety of application methods and plant-soil combinations which must be factored into the pretreatment process design. Another significant consideration in relation to land application are production objectives which simply stated are: 1) to derive the largest economical recovery of the agronomic nutrients in swine waste or 2) to minimize the size, operation, and maintenance requirements of the land application activity. Both objectives are present by choice or constraints in the swine industry and since these are opposite goals no single process design or selection can be ubiquitous. Pretreatment is thus determined by the producer objectives with respect to the terminal receiver and emphasis will be given to process performance for both nutrient conservation and high level waste reduction.

Waste Constituent Categories

The discussion of pretreatment process performance with respect to the plant-soil receiver must center on individual waste constituents. As a brief introduction, the parameters included in this study are, in relative priority, as follows: 1) nitrogen (all forms), 2) salts and specific cations, 3) organics, 4) microorganisms and pathogens, and 5) nuisance factors and distinguishing constituents. The emphasis on nitrogen reflects the fact that for the majority of situations nitrogen is the land limiting constituent (LLC). That is, in comparison to other constituents, nitrogen application rates require the most land area. In addition, nitrogen is a valuable nutrient in swine waste for plant growth. As these facts have become better understood, literature emphasis has shifted to reflect the concern for nitrogen as the controlling constituent.

Salt and cation content of swine waste is the largest exception to the emphasis on nitrogen especially in certain water deficit regions and for pretreatment processes which greatly reduce nitrogen levels. Salt and cation effluent content then become the land limiting constituents. Within the literature there is generally less information on this aspect of swine waste, but since these elements are generally conservative a priori calculations can be used to advantage.

Concern for organic constituents is useful in understanding treatment mechanisms and has secondary impact on pretreatment processes as the substantial oxygen demand. However, in terms of the land receiver, organic matter is beneficial but does not impose a substantial economic restriction on land area. The carbonaceous level in swine waste is high; hence, most pretreatment processes are operated in the anaerobic or facultative modes.

The microorganism and pathogenic microorganism aspects of swine waste have received relatively less research attention. The reasons are principally that the levels are so high that microbial pretreatment processes are not organism restricted and because disease for swine and other species has not been a significant or recognizable factor in reasonably managed systems. Certain pretreatment processes such as methane formation and refeeding have accelerated interest in microbial information and added emphasis to delineating disease potential.

Nuisance characteristics of swine waste such as odor and hair are difficult to quantify and often difficult to control. Relatively little research on the practical problems of controlling these factors has occurred.

Pretreatment Categories

Degradation of swine waste begins shortly after defecation as the manure is exposed to the atmosphere. Since there is a lag time before wastes are removed from the animal production facility, Figure 3, each production unit must be considered in regard to inherent waste degradation potential. That is, a production unit, such as a concrete floor or a slotted floor-pit system in which waste resides for an extended period, can result in constituent loss, thereby lessening any further pretreatment process costs. Conversely, if the producer objective is conservation, such production units can represent uncontrolled loss of utilizable materials. Other production units such as frequent gutter flushing result in rapid removal of raw waste and have little pretreatment effect. Therefore, the impact of production unit will be included in this waste management study as a part of the total system.

Construction and use of a separate process in addition to the actual production unit, is broadly classed as pretreatment prior to terminal receiver, Figure 3. Many possibilities regarding physical location of these pretreatment processes within, partially within, adjacent to, or distant from the actual production units exist, so such pretreatment processes are considered as separate units in series. The emphasis

will be placed on losses, conversions, and separations which occur through representative pretreatment units thereby increasing the transferability of individual reported research results.

STATE-OF-THE-ART OBJECTIVES

A state-of-the-art report serves as a documentation benchmark and a mechanism for solving the continually extant problem of defining the differences between current knowledge and future goals. The overall approach is to recycle or reuse the wastes generated by the swine production industry, to advance the progress of environmental protection, and to maintain a strong food production industry. The industry state-of-the-art report for swine production and waste treatment displays pertinent literature data, evaluates current information, and documents analyses to put the whole industry in a congruent format. In listing references in the text or on tables, only the first author and the date are listed. This allows bibliographic organization alphabetically and presents the archival perspective. Specific objectives of this report are as follows:

- 1) To detail the defecated waste load and discernable effects of swine production units. Emphasis is on parameters important to the terminal receivers and major regional and seasonal effects as are documented or extrapolatable from the present state of knowledge.
- 2) To describe qualitatively and quantitatively the performance of unit processes used in the pretreatment of swine waste prior to land application. The recycling byproduct recovery processes for swine wastes will also be included.
- 3) On a representative basis, the relative economic and environmental impact of the various production and pretreatment units will be addressed.

The impact on and design of the terminal plant-soil system for the full strength waste and pretreatment effluents are not reviewed in excruciating detail by this report because: 1) recent comprehensive reviews on land application of swine waste, animal waste, municipal waste, and land-based system technology exist (Wilson 1968; Environmental Protection Agency 1973, 1973a; McJunkin 1973; Ramsey 1974; Powers 1975), 2) the mechanisms and performance of the plant-soil systems are dependent on waste constituents, and 3) the land-based system is much more site-specific than production and pretreatment units thus making localized guidelines directive of land use (Maine 1972, Powers 1974).

SECTION IV

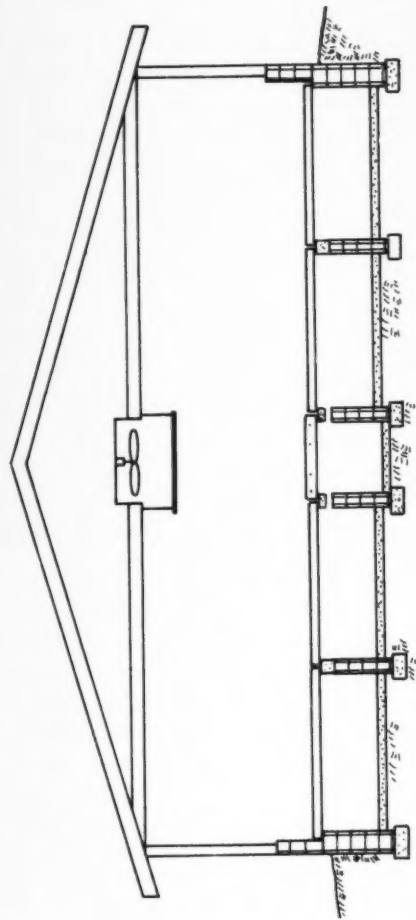
SWINE PRODUCTION UNITS

HOUSING CATEGORIES

There is a wide spectrum of swine housing facilities which, if considered in every detail, probably translates into a different unit for every producer. However, with respect to waste management and the effects on the defecated waste load, certain commonalities emerge for easy categorization of swine housing. Three facilities groupings, 1) buildings with slotted floors, 2) units with concrete slab floors, and 3) open dirt or pasture lots, include virtually all producer situations. The first grouping has the most direct method of waste collection, storage, and removal to subsequent pretreatment; hence, there is the less opportunity for waste loss. Concrete floor units generally are cleaned daily and are often more exposed to the climatological elements; hence, are intermediate in terms of waste degradation. The largest effect on waste load is associated with drylot or pasture units; hence, the third grouping.

Slotted Floor Buildings

Buildings with slotted floors consist of two types, those with only a portion of the floor space slotted and those with the entire floor slotted. A good discussion of floor design and building recommendations can be found in a number of documents (Midwest Plan Service 1972, 1975; North Carolina Agricultural Extension Service 1974). Beneath the slotted floor is a storage pit, Figure 4. Hand labor for pen cleaning is greatly reduced with totally slotted floors, thus contributing to greater utilization of total slats in completely confined units. An oxidation ditch or lagoon is directly below the slotted floor in less than 5 percent of such units.



TOTAL SLAT UNDER ROOF

Figure 4. Schematic of swine production facility with totally slatted floor, manure storage pit, and ventilation system.

Minimal scraping or water cleaning is needed with totally slatted floors. Underfloor or pit ventilation systems have been recently developed to reduce odor and improve environmental conditions (Driggers 1974, Ross 1975). Stocking density in finishing operations with total slats is approximately 0.65-0.75 m²/hog. For slatted farrowing units with crates, the area per sow and litter is about 3.6 m². Since the pit extends under the entire pen area, the waste storage capacity is from 0.44 to 0.88 m³ per 45-kg hog as the pit depth is usually between 0.62 and 1.2 m. For minimal excess water, there are approximately 120 to 240 days and 180 to 360 days of storage for finishing and farrowing units, respectively.

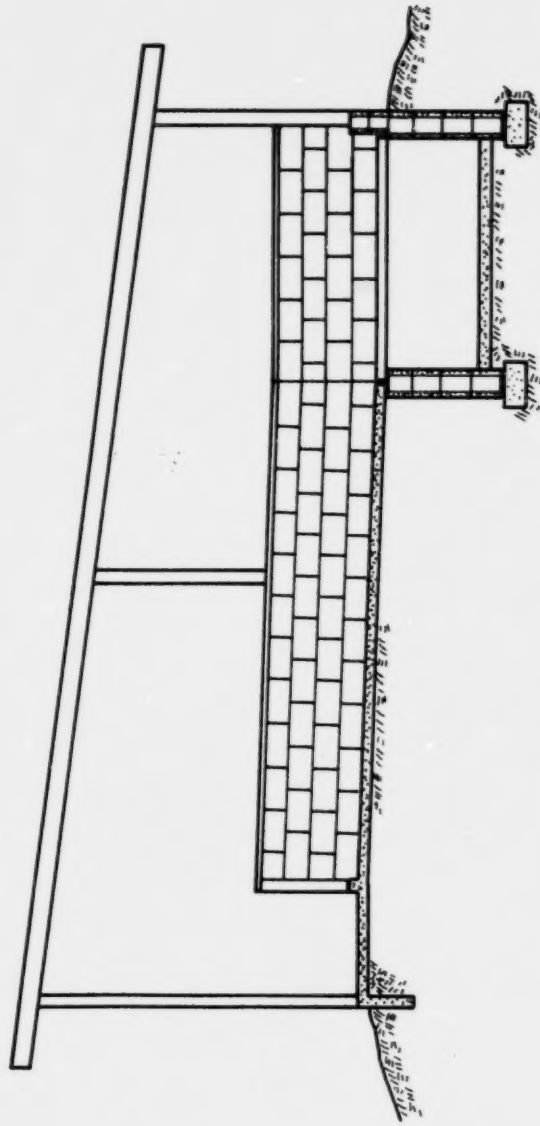
With partial slats, manual scraping or hose flushing is employed to move any waste not defecated over the slatted area, thereby incurring greater labor requirements than totally slatted buildings. In terms of swine production, the partially slatted units were designed for "farrow-to-finish" operation. Pen space recommendations are on the basis of 0.75 m² per hog with about one third of the pen slatted, Figure 5. The storage pit is only under the slatted area and ranges from 0.62 to 1.2 m in depth. Storage volumes are thus 0.16 to 0.31 m³ per hog or approximately 45 to 85 days of storage if little excess water is used.

Solid Concrete Slab Floor Units

Two general types of units exist in this category, 1) units in which 100 percent of the floor area is under roof and 2) concrete pad or paved lots in which 50-70 percent is under roof. Swine waste in these structures is removed usually every 1 to 3 days. Under winter conditions, less frequent waste removal is sometimes practiced.

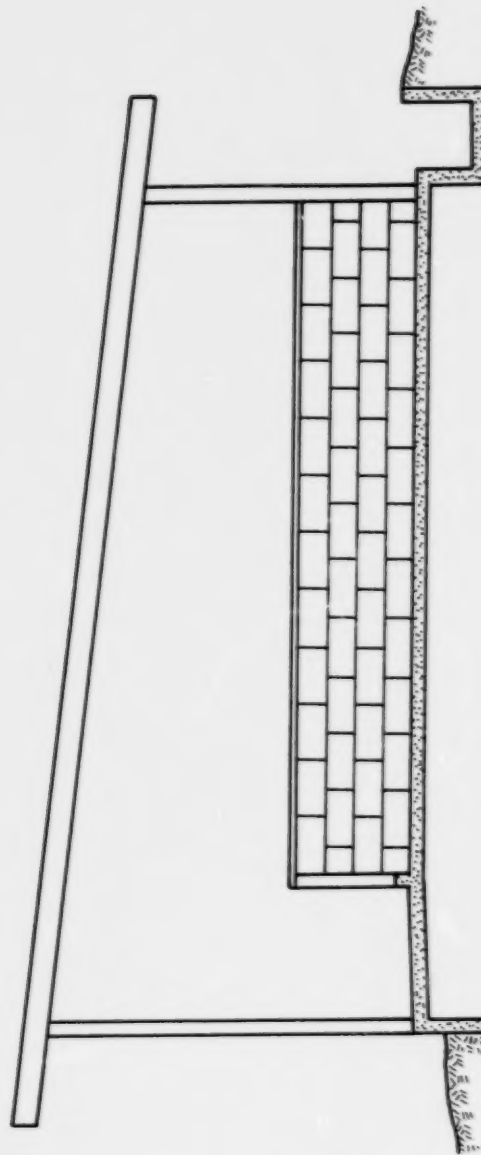
In group 1, the original buildings allowed 1.1 to 1.4 m² of floor space per market animal, Figure 6. Newer units allowed 0.9 m² per market animal with the entire area under roof. The majority of production units with solid concrete floors are only partially roofed. Wood shavings, straw, or sawdust bedding is used extensively in farrowing houses because of its insulating and absorptive characteristics. The bedding is an added waste load which is scraped and disposed in solid form in cold regions and handled as a slurry in warm areas.

A sloping gutter along one side of the concrete floor serves as the collecting device for the waste as it is scraped or washed from the floor. In common practice, the waste from the gutter might be turned loose to run as it may or enter a temporary storage tank, or a lagoon.



PARTIAL SLAT UNDER ROOF

Figure 5. Schematic of swine production facility with partially slatted floor and manure storage pit.



**TOTAL ROOF , CONCRETE SLAB WITH GUTTER
(CLAYTON UNIT)**

Figure 6. Schematic of totally roofed concrete slab swine production unit.

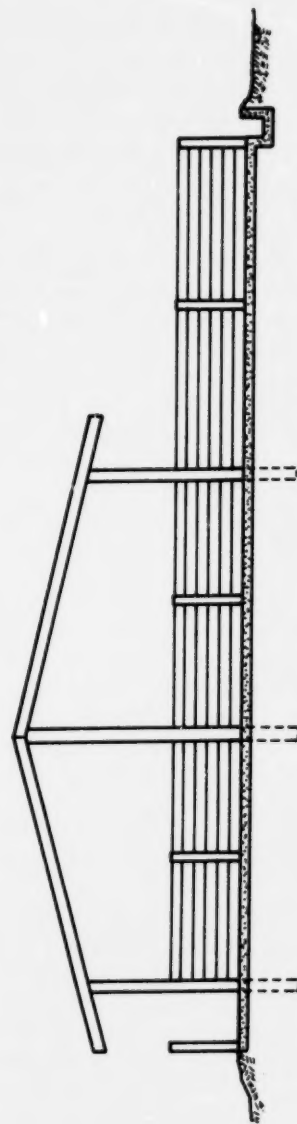
Waste handling by pen scraping and occasional water wash reduces the total waste volume by minimizing water usage. High pressure, low volume hose systems allow more rapid and efficient cleaning and thus large reductions in washwater quantities. Drinking cup spillage, fogging water, and urine continuously flow into the collection gutter. Tree leaves collecting on roofs and emptying into gutters have a profound impact on subsequent waste pretreatment units and should be avoided to improve long term waste management (Baker 1975). Rainfall and roof runoff or drainage that enters the waste collection and conveyance system contribute to wastewater volumes that must be handled. Because of the number and sources of extra water input, some of them uncontrollable, the waste volume from such a solid concrete unit is expressed as a range of commonly encountered data for waste removal every 1-2 days.

The development of automated wash systems for concrete floor-gutter units using recycled lagoon effluent has allowed more frequent and convenient washing along with a tremendous reduction of fresh water usage. Health and operational hazards have not yet been found to cause any concern or limitation. Iowa State researchers (Willrich 1966, Smith 1971, Koelliker 1972) report that the quality of renovated flush water is far less important than the quantity. The frequent removal of fresh excreta minimized odor, and the running water attracts the hogs to play and defecate in the shallow gutter. Gutter flush and daily low pressure hose washing produce to 10 to 100 times the hydraulic waste load (Midwest Plan Service 1975).

The second grouping of solid concrete floor units is basically a paved feedlot with a portion of the area covered for animal protection, Figure 7. On a per market animal basis there are typically 0.75 m² of shelter and 0.75 m² of unsheltered lot. Most of the waste is scraped from the pad and hauled for land application. Cleaning frequency during warm periods is 1 to 2 times/wk to minimize odor. During cool periods, cleaning is approximately monthly due to scrap and land access difficulties.

Open Dirt or Pasture Lot Production

Open dirt lots are still the most common type of swine facility with approximately 50 percent of the total number of hogs finished in open lots or pastures. The producer who feeds out hogs on dirt is substituting labor and land for capital investment. Where labor is plentiful, relative to capital, a producer may be able to feed out two or three times as many hogs in an open lot system as he could afford in confined housing. Open dirt or pasture production units have the lowest density of hogs but are considered confinement operations since animals are fed within fenced areas, Figure 8.



PARTIAL ROOF , CONCRETE SLAB WITH GUTTER

Figure 7. Schematic of partially roofed, concrete slab swine production unit, "concrete feedlot".

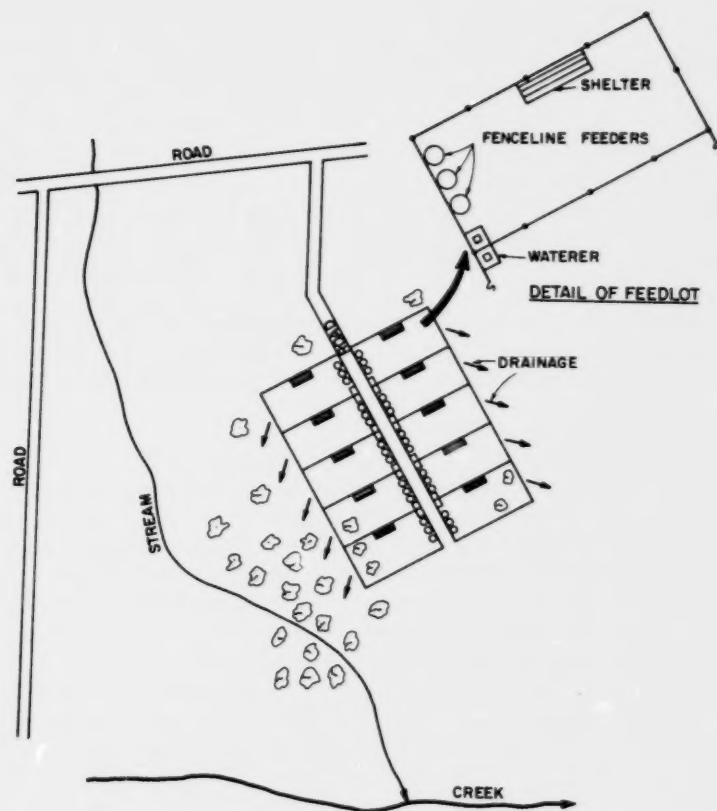


Figure 8. Schematic of swine drylot system.

Wastes can be utilized naturally by the soil-vegetation if animal densities are low enough to maintain pasture conditions. Recommended animal densities are 60 market hogs per hectare (Midwest Plan Service 1972) and 50 to 75 animals per hectare (Dobson 1975) on permanent pasture such as Bermuda Grass or Fescue and Ladino clover. Beyond this density, bare areas will begin to appear. For pastures to survive, animals must be removed during the dormant or non-growing season or lots rested by a rotation scheme. Pastured situations do not represent feedlot conditions because vegetative cover is maintained and wastes are applied at recommended nitrogen rates (65 hogs/hectare), thus should not be subject to effluent limitations. However, the proportion of animals finished on pasture is small compared to those finished on dirt lots.

Lots with 100 or more hogs per hectare will not support vegetative cover. The most widely practiced stocking density ranges from 125 to 500 animals per hectare, but densities up to 1,200 per hectare are employed in some cases. It is estimated that less than 10 percent of hogs produced on open dirt are in lots stocked below 125 animals per hectare and less than 15 percent in lots stocked above 500 per hectare. Actual lot location as well as stocking densities are determined by such factors as annual rainfall, soil type, drainage, topography, temperature, vegetation and shade cover, and proximity to surface waters.

Soil types generally determine how heavily a lot can be stocked and how much runoff will occur. Higher stocking densities can be maintained on sandy soils which are well-drained and have high infiltration capacities. Manure buildup and compaction are minimal since the animal activity tends to keep the waste well mixed with the sandy surface. Drylots are rotated after two groups of animals or one year's production to control disease and parasites and to allow rejuvenation of the soil surface. These lots are then seeded to grasses or allowed to remain fallow for at least two years before being put back into production. However, many producers continue to develop new land to take advantage of existing wooded areas for shade cover. Trees are rapidly killed, however, in densely populated swine lots due to soil compaction and stripping of the bark by the hogs. These practices necessitate the need for development of new lots and the construction of sun shades in existing lots. Some producers use a row of fogging or spray nozzles for cooling the animals during extended periods of high temperatures.

Lower stocking densities are usually necessary on heavier clay soils or highly organic soils. In low-rainfall areas, surface compaction occurs resulting in a manure pack characteristic of high density beef feedlots. Infiltration is drastically decreased, causing more rainfall runoff. When these lots are taken out of rotation, any manure buildup will usually be disked into the soil or scraped up and spread on crop land. In addition, the lot may be deep plowed with subsoilers to break up the surface compacted layer and increase infiltration. In high-rainfall areas, animal activity in dirt lots tend to cause the heavy soils to become very muddy. This condition decreases feed utilization efficiency and increases the potential for odor generation, mosquito production and diseases. Animal mortality rates are higher compared to confined housing. When these lots are taken out of rotation, the soil surfaces may be chemically treated for disease and parasite control.

Hogs raised on dirt lots are usually fed by self-feeding finishing troughs. These feeders are located just inside the fenceline at the highest elevation within the lot to obtain maximum drainage away from the feeders. An approximate 3-m concrete or wooden pad usually surrounds the feeders to prevent the area from becoming a hog wallow; however, since hogs tend to congregate here, muddy and compacted soil conditions usually prevail. It is in this vicinity that most of the waste is defecated.

Many swine drylots are located on topography sloping toward a drainage-way or stream but are separated from the stream by a wooded or vegetated buffer strip. In addition, large swine production units characteristic in the southeastern Coastal Plains usually drain toward a low-lying swampy area through which an ill-defined stream traverses. These conditions constitute a living, biological filter and tend to improve the quality of drylot runoff before it reaches a stream.

Housing Trends

Labor availability and the rising costs of feed and materials have moved the swine industry steadily toward more efficient systems. That is, labor efficiency, high feed conversion, and low mortality are requisite criteria for successful operations. In terms of housing units, the need to reduce labor costs, especially for waste cleaning, has reduced the desirability of the concrete pad and solid concrete floor units. Dirt lots and total confinement are more attractive alternatives.

Confinement houses offer reduced mortality, higher conception rates, and enhanced feed conversion (Christenson 1972, Driggers 1973a, Driggers 1973) and have been cost effective in a number of instances (Stanislaw 1975, Driggers 1976). The high investment costs of

confinement houses has assured the continued use of the low labor alternative - dirt lots which are more appropriate for finishing operations. Pasture operations require large land areas and significant labor but are very attractive in terms of minimal waste management. However, in terms of existing swine production units, there are slow but steady changes over the last five years toward total confinement.

MAGNITUDE AND DISTRIBUTION OF SWINE POPULATION

1969 Census

United States census of agriculture data for 1969 reproduced in Table 1 show total number of farms and hogs sold in 1969 for all farms and for farms with income over \$2,500 under the four subcategories: 1) total, 2) farms marketing 200-499, 3) farms marketing 500-999, and 4) farms marketing 1,000 and over. The 23 states listed in this table account for 95 percent of the total hogs marketed in the United States. During 1969, approximately 68 million or 80 percent were produced by the top ten states and another 20 percent were produced by the other 13 states included.

From the 23 states listed in the 1969 census, farms selling over 1,000 hogs and pigs accounted for 13 percent of the market. Farms selling between 500-999 hogs and pigs accounted for 20 percent of the total market. Farms selling 200-499 hogs and pigs accounted for 36 percent of the total market. Therefore, producers selling less than 200 animals accounted for 31 percent of the total market in these 23 states, or approximately 26 million hogs and pigs.

1975 Inventory

Data supplied by the Crop Reporting Service (USDA 1975) estimated the inventory of hogs and pigs on December 1, 1975, as 49.6 million head, 10 percent less than a year earlier and 19 percent below December 1, 1973. This is the lowest total hog population for at least the last 12 years as shown on the barograph in Figure 9. The hog and pig inventory numbers for breeding, market and total as of December 1, 1975, for the 14 quarterly states listed in Table 2 show a total of 41.9 million; down 11 percent from a year earlier, and down 21 percent from two years ago. These 14 quarterly states, which include 10 corn belt states plus the southeastern states of North Carolina, Georgia, Kentucky and Texas, account for 84 percent of the United States hogs and pigs inventory.

Table 1. TOTAL NUMBER OF HOGS AND PIGS SOLD IN 1969.
Source: 1969 U.S. Census of Agriculture

All Farms			Farm Income Over \$2500.00							
State	Farms Number	Hogs & Pigs Number	Total		Farms Marketing 200 to 499		Farms Marketing 500 to 999		Farms Marketing 1000 & Over	
			Farms Number	Hogs & Pigs Number	Farms Number	Hogs & Pigs Number	Farms Number	Hogs & Pigs Number	Farms Number	Hogs & Pigs Number
1. Iowa	88,196	20,826,437	84,937	20,725,145	29,913	9,095,109	7,960	3,160,341	1,433	2,061,531
2. Illinois	51,090	10,971,882	46,348	10,824,545	12,129	3,728,236	4,178	2,771,838	1,299	1,930,406
3. Indiana	36,699	7,207,719	32,063	7,070,260	7,891	2,380,210	2,373	1,701,268	804	1,297,969
4. Missouri	69,701	7,219,227	41,828	7,009,350	8,639	2,554,722	1,936	1,273,699	491	798,575
5. Minnesota	39,058	5,488,114	36,700	5,421,645	6,918	2,001,984	1,370	898,920	269	397,763
6. Nebraska	31,157	4,788,158	29,740	4,746,914	6,423	1,869,637	1,124	728,949	244	381,478
7. Ohio	29,358	4,103,601	24,789	3,990,337	4,582	1,372,935	1,174	782,282	333	494,476
8. Wisconsin	25,542	3,018,324	23,495	2,958,831	3,642	1,006,820	672	439,380	116	186,382
9. Kansas	21,071	2,934,653	19,100	2,877,948	3,308	973,057	718	471,445	225	411,225
10. S. Dakota	19,346	2,704,669	18,832	2,689,273	3,533	1,006,566	498	315,658	116	180,705
11. N. C.	26,248	2,301,048	19,321	2,146,895	1,562	450,552	413	276,353	270	625,955
12. Georgia	21,486	2,287,925	16,034	2,156,747	2,167	624,903	474	308,517	214	362,966
13. Kentucky	25,387	2,074,441	19,333	1,952,063	1,822	532,671	391	259,530	156	235,444
14. Tennessee	27,959	1,870,686	17,517	1,623,421	1,517	430,128	251	164,217	76	129,079
15. Alabama	16,938	1,292,982	10,256	1,155,101	1,012	291,283	207	138,785	98	199,944
16. Texas	19,083	1,450,095	13,456	1,539,057	1,300	380,592	349	234,490	192	367,837
17. Michigan	10,636	1,109,623	8,064	1,057,568	1,021	303,744	288	189,810	104	176,879
18. Miss.	10,033	536,222	4,904	459,835	318	90,311	89	58,236	60	123,892
19. S. C.	10,106	534,342	5,762	463,956	376	106,355	96	60,440	45	70,232
20. Virginia	12,247	845,756	8,859	781,741	666	193,809	159	104,201	52	117,108
21. Penn.	12,112	842,620	9,086	775,211	931	401,159 (200 and over)	Not available		Not available	
22. Oklahoma	8,217	527,289	6,216	484,649	424	120,877	83	54,947	31	53,955
23. N. Dakota	7,518	499,822	7,188	491,504	462	131,589	67	42,572	21	27,651
TOTALS		85,635,635		83,401,972		30,047,269		16,436,098		10,631,472

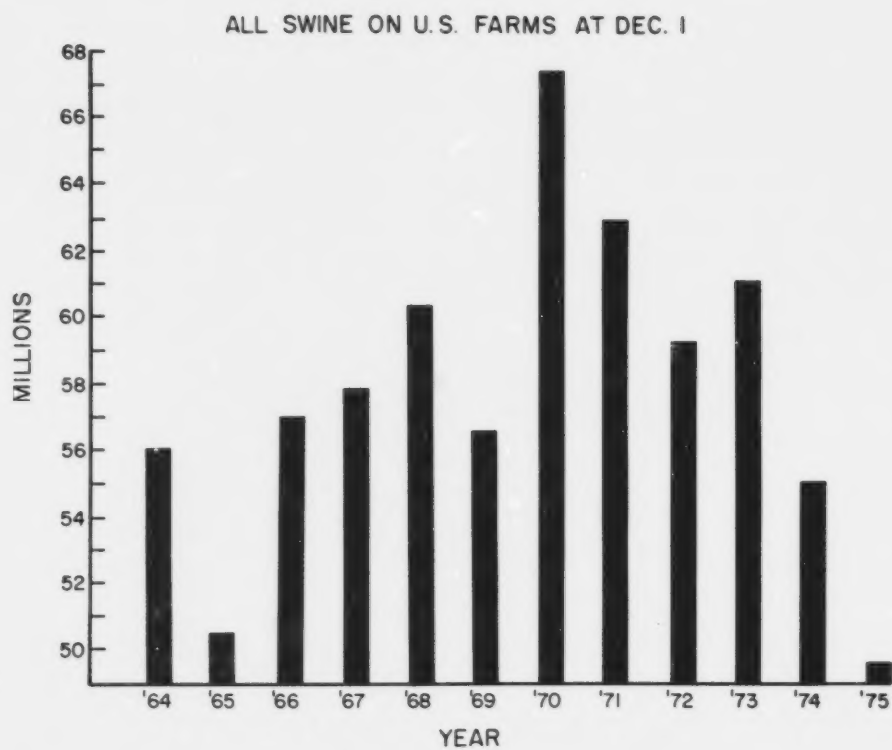


Figure 9. Swine inventory of animals on-farm, December 1.

HOGS AND PIGS: INVENTORY NUMBERS, SPPEDING, MARKET AND TOTAL, DECEMBER 1, 1974-75									
STATE	SPPEDING				MARKET				TOTAL
	1974		1975		1974		1975		1974
	1974		1975		1974		1975		1974
	NUMBER	% OF 1974	NUMBER	% OF 1974	NUMBER	% OF 1974	NUMBER	% OF 1974	NUMBER
	1000 HEAD	PERCENT	1000 HEAD	PERCENT	1000 HEAD	PERCENT	1000 HEAD	PERCENT	
GA	244	93	134	1072	80	1500	1300	42	
ILL	880	823	103	570	477	84	4500	5600	84
IND	538	473	147	374	3127	89	4300	3900	91
IOWA	1740	1927	105	1160	10773	92	13400	12600	94
KANS	220	271	101	1522	1419	93	1740	1650	94
KY	164	148	102	934	832	89	1100	1000	91
MINN	518	465	98	3182	2535	80	3700	3600	81
MO	550	512	92	3342	2688	80	3900	3800	82
NEBR	380	405	113	2600	2295	85	3050	2700	89
N C	274	304	111	1616	1596	90	1900	1900	101
OHIO	244	248	98	1686	1415	84	1950	1675	86
S DAK	238	245	103	1462	1155	79	1700	1400	82
TEX	127	122	96	813	654	81	940	780	83
WIS	228	205	90	1172	945	81	1400	1150	82
TOTAL									
14 STS.	6243	6348	101	40847	35487	87	47170	41855	89
ALA	138	148	107	812	672	83	950	820	86
ALAS	20	20	100	90	50	56	1.10	.70	64
ARIZ	12	12	100	87	85	98	90	97	98
ARK	68	77	113	202	225	111	270	302	112
CALIF	16	26	163	104	112	104	124	138	111
COLO	34	76	106	246	254	103	280	290	104
CONN	1.3	1.6	123	5.2	5.2	100	6.5	6.4	105
DEL	10	10	100	40	45	113	50	55	110
FLA	45	76	76	247	206	83	292	240	82
HAW	9	9	100	52	49	94	61	58	95
IDAH0	13	12	92	97	78	80	110	90	82
LA	38	40	105	137	130	95	175	170	97
MAINE	1.4	1.4	100	5.6	5.6	100	7.0	7.3	104
MD	31	35	113	192	200	104	223	235	105
MASS	9	9	100	45	46	102	54	55	102
MICH	92	98	107	623	602	97	715	700	98
MISS	71	47	94	385	284	74	456	351	77
MONY	28	28	89	182	120	74	190	145	76
NEV	1.4	1.4	100	8.4	7.6	88	10.0	9.0	90
N H	1.7	1.3	76	7.0	7.4	106	8.7	4.7	100
N J	7	7	100	44	91	103	95	98	103
N MEX	12	10	83	54	43	80	66	53	80
N Y	15	15	100	87	75	86	102	90	88
N DAK	45	41	136	277	289	104	322	350	109
OKLA	48	44	100	262	252	96	310	300	97
OREG	13	14	123	82	74	90	95	90	94
PA	82	43	101	551	577	105	633	660	104
R I	1.4	1.4	100	7.4	7.4	103	8.8	9.0	102
S C	90	78	87	520	462	89	610	540	89
TENN	101	140	149	670	770	113	780	920	118
UTAH	6	9	133	35	35	100	41	43	105
VT	1.8	1.3	103	2.4	3.2	133	3.2	4.5	141
VA	40	122	177	506	538	106	875	660	115
WASH	10	10	100	65	61	94	75	71	95
W VA	7	6	86	48	44	92	55	50	91
WYO	6	5	83	33	25	76	39	30	77
U.S.	7416	7634	103	47046	41968	89	55062	49602	90

Table 2. CENSUS BY STATE FOR ON-FARM HOG POPULATIONS, DECEMBER 1, 1974 AND 1975.

1975 Pig Crop

The United States pig crop for December, 1974, (USDA 1975) through September, 1975, was 71.3 million head, 15 percent below a year ago and 19 percent less than 1973. The December, 1974, to May, 1975, pig crop at 35.5 million was down 21 percent from a year earlier and June-November, 1975, pig crop at 35.8 million was 8 percent lower than the same period in 1974.

The 5 million sows farrowed during June-November, 1975, was 9 percent below the same period a year earlier. Average litter size during this period was 7.21 pigs, compared with 7.11 in June-November, 1974.

Value per head for all hogs and pigs as of December 1, 1975, was \$80.30 as compared to \$45.10 for 1974 and \$60.40 for 1973. Correspondingly, the total value for 1975 was \$3.98 billion compared with \$2.48 billion in 1974 and \$3.69 billion in 1973, Table 3.

Farrowing Intentions

Hog producers in the United States intend to farrow 5.4 million sows during December, 1975-May, 1976, (USDA 1975), an increase of 8 percent from December, 1974-May, 1975, but 16 percent less than the same 6-month period two years earlier. These intentions indicate a pig crop of 38 million, 7 percent more than a year earlier, but 16 less than December, 1973-May, 1974. Intentions in the 14 quarterly states are for 2 million sows to farrow during the three month period, December, 1975, to February, 1976, up 10 percent. If these intentions are realized, the expected increase would be the first since 1971 for this 6-month period. As the barograph in Figure 9 shows, production intensity of hogs at the national level usually follows cycles over a relatively short number of years and are responsive to market conditions.

Production Unit Distribution

Swine Specialists Survey--

Data were collected from knowledgeable swine specialist personnel in the top ten swine producing states, which account for about 85 percent of total United States hog production, to assess the fraction of hogs grown in typical production units, Table 4. Evaluation of these data indicates that approximately 30 percent of the market hogs in the United States were produced in concrete floor units, that is partially or totally roofed houses or concrete pad types units. About 20 percent of the swine were grown in slotted floor houses, with the majority of the production units having partial slotted rather than total slotted

HOSES AND PIGS: NUMBER OF OPERATIONS WITH HOSES, INVENTORY, VALUE PER HEAD, AND TOTAL VALUE, DECEMBER 1, 1974-75

STATE	OPERATIONS WITH HOSES		INVENTORY		VALUE PER HEAD		TOTAL VALUE	
	1974	1975	1974	1975	1974	1975	1974	1975
	NUMBER		HEAD		DOLLARS		1000 DOLLARS	
AK	26000	24000	1500	1300	43.50	71.3	49164	92300
AL	48000	41000	6500	5600	46.00	81.3	209000	454400
AR	33000	28000	4300	3900	43.00	78.00	184900	164200
AS	80000	74000	13400	12000	49.50	86.50	663300	1089000
CA	18000	15000	1740	1650	38.50	77.00	47375	127000
CT	38000	32000	1100	1000	42.50	77.00	46750	77000
DE	39000	34000	3700	3000	46.50	81.00	172050	243000
FL	40000	42000	3000	3200	40.50	84.50	157950	270400
GA	29000	24000	3050	2700	44.00	85.50	134700	230400
HI	44000	28000	1800	1900	44.00	73.00	43180	138700
IL	28000	26000	1040	1675	39.00	80.50	76050	134400
IN	17500	15000	1700	1400	44.50	84.50	79050	118300
IA	20000	24000	940	780	43.50	67.50	40890	52600
KS	25000	24000	1400	1150	44.50	73.00	62300	83950
LA								
ME								
MD								
MA								
MI								
MINN								
MO								
NE								
NH								
NJ								
NM								
NY								
OH								
OK								
OR								
PA								
RI								
SC								
SD								
SE								
SH								
SI								
SK								
SN								
SP								
ST								
SW								
TX								
UT								
VA								
WA								
WI								
WY								
U.S.	771700	690200	45000	40000	45.10	80.30	2401000	3002000

Table 3. VALUE OF SWINE INVENTORY ON-FARM, BY STATES, DECEMBER 1, 1974 AND 1975.

Table 4. PROPORTION OF SWINE GROWN ACCORDING TO PRODUCTION UNIT
AS ESTIMATED BY KNOWLEDGEABLE UNIVERSITY SPECIALISTS
IN EACH STATE

State	Solid Concrete Floor Units	Buildings with Slotted Floor	Pasture or Dirt Lot	Information Source
Iowa	30%	10%	60%	Estimate
Illinois	20 - 25%	12 - 15%	65%	Estimate
Indiana	20 - 25%	20 - 25%	50%	Estimate
Missouri	25 - 30%	20 - 25%	50%	Estimate
Minnesota	75%	20%	5%	Estimate
Nebraska	35%	15%	50%	Estimate
Ohio	33%	11%	56%	Estimate
N. Carolina	20%	10%	70%	Survey by Jones (Jones 1972)
Kansas	15 - 25%	35%	40 - 50%	Estimate
S. Dakota	78%	22%	...	Estimate
Selected Average Value for United States	30%	20%	50%	

floors. About 50 percent of the swine in the United States are produced on pasture or dirt lot as indicated by the selected average values summarized in Table 4.

National Poll--

Summary copies of the 1971 and 1974 survey conducted by the National Pork Producers Council are presented in Tables 5 and 6 to compare trends noted by this poll over the last several years. The 1971 poll data represented 1,499 respondents to the 50,000 questionnaires distributed, or producers of only about 2 percent of total hogs marketed in 1971. Comparison of the 1971 and 1974 poll data shows many similarities in production trends such as: age bracket, type of production, hogs marketed, farrowing facilities, finishing facilities, and waste management systems. The major change appears to be greater use of slatted floors, increasing from about 14 percent in 1971 to 37 percent in 1974, with 1974 data showing a further differentiation between totally slatted (10 percent) and partially slatted (27 percent). This increased utilization of slatted floor facilities verifies indicated national trends to totally enclosed units with slatted floors as the most cost-effective for both production and waste management.

Data for yearly pork producer polls continue to show that about 90 percent of the respondents practice terminal land application. Illinois data (Day 1975) shows that oxidation ditches serve about 120,000 pigs or about 0.2 percent of the total on-farm hog population are corroborated by poll data indicating that only about 0.2 percent of the respondents had oxidation ditches.

In overview, it appears that responses came from producers who have made substantial investments in recent years, since about 70 percent were between the ages of 20 and 49 and about 60 percent produced over 200 hogs in 1974. It also appears that the trend is toward larger production units because between 1971 and 1974 the number producing under 500 hogs decreased, while the number producing above 500 hogs increased with the greatest differential being in the group between 1,000 and 2,999 hogs marketed. Although the representativeness and accuracy of poll data must temper major conclusions, it does appear that producers who are ready to characterize their production and waste management techniques have high density units with either slatted or concrete floors and exercise terminal land application.

State-Wide Survey, North Carolina-

During 1974, a survey was conducted throughout North Carolina on a county-by-county basis to obtain data on the number of producers,

Table 5. RESULTS OF NATIONAL PORK PRODUCERS COUNCIL POLL OF MEMBER FARMERS, 1971

PRODUCTION TRENDS:

1. Into which age bracket do you fall:

(1) <u>13.5%</u>	20-29	(4) <u>20.6%</u>	50-59
(2) <u>28.8%</u>	30-39	(5) <u>5.6%</u>	60-69
(3) <u>29.8%</u>	40-49	(6) <u>1.1%</u>	Over 70

2. Describe your hog operation:

(1) <u>5.7%</u>	Feeder pigs only	(3) <u>72.0%</u>	Farrow to finish
(2) <u>7.7%</u>	Finish only	(4) <u>3.7%</u>	Combination

3. How many hogs did you market for slaughter in 1971

(1) <u>12.8%</u>	0-200	(4) <u>17.6%</u>	1,000-3,000
(2) <u>33.1%</u>	200-500	(5) <u>3.6%</u>	3,000 up
(3) <u>30.6%</u>	500-1,000		

4. Describe your farrowing facilities:

(1) <u>70.0%</u>	Central farrowing house
(2) <u>5.7%</u>	Individual houses
(3) <u>1.7%</u>	Pasture farrowing
(4) <u>14.3%</u>	Combination

5. Check your finishing facilities:

(1) <u>26%</u>	Enclosed building	(3) <u>10%</u>	Pasture
(2) <u>36%</u>	Open shed building	(4) <u>23%</u>	Combination

6. Check type of flooring in facilities:

(1) <u>13.8%</u>	Slotted	(3) <u>20.9%</u>	Both
(2) <u>50.4%</u>	Solid	(4) <u>10.0%</u>	Other

7. Check your waste management pattern:

(1) <u>69.5%</u>	Manure spreader
(2) <u>14.1%</u>	Honey wagon
(3) <u>4.9%</u>	Lagoon
(4) <u>0.2%</u>	Oxidation ditch
(5) <u>3.1%</u>	Combination
(6) <u>5.5%</u>	Natural drainage

Table 6. RESULTS OF NATIONAL PORK PRODUCERS COUNCIL POLL OF MEMBER FARMERS, 1974

PRODUCTION TRENDS:

1. Into which age bracket do you fall:

(1) <u>13.7%</u> Under 30	(4) <u>20.5%</u> 50-59
(2) <u>28.9%</u> 30-39	(5) <u>4.7%</u> 60-69
(3) <u>30.9%</u> 40-49	(6) <u>1.2%</u> 70 or over

2. Describe your type of hog production:

(1) <u>6.1%</u> Feeder pigs only	(3) <u>74.3%</u> Farrow to finish
(2) <u>6.6%</u> Finish only	(4) <u>12.4%</u> Combination

3. How many hogs did you market for slaughter in 1973:

(1) <u>11.1%</u> Under 200	(4) <u>23.2%</u> 1,000-2,999
(2) <u>27.2%</u> 200-499	(5) <u>4.1%</u> 3,000 and up
(3) <u>32.3%</u> 500-999	

4. What is the maximum number of hogs weighing more than 50 lbs. that you have on your farm at one time:

(1) <u>64.7%</u> Under 500	(4) <u>1.6%</u> 1,500-1,999
(2) <u>23.9%</u> 500-999	(5) <u>0.9%</u> 2,000-2,499
(3) <u>6.3%</u> 1,000-1,499	(6) <u>1.9%</u> 2,500 and up

5. Describe your farrowing facilities:

(1) <u>72.1%</u> Central farrowing house
(2) <u>5.2%</u> Individual houses
(3) <u>1.5%</u> Pasture farrowing
(4) <u>16.3%</u> Combination of above

6. Describe your finishing facilities:

(1) <u>26.0%</u> Enclosed building	(3) <u>8.6%</u> Pasture
(2) <u>38.1%</u> Open front building	(4) <u>23.9%</u> Combination of above

7. Describe type of flooring in facilities:

(1) <u>10.2%</u> Totally slatted	(4) <u>11.7%</u> Combination of above
(2) <u>26.8%</u> Partly slatted	(5) <u>8.0%</u> Other
(3) <u>46.0%</u> Solid concrete	

8. Describe your waste management system:

(1) <u>62.6%</u> Manure spreader (open wagon)
(2) <u>21.0%</u> Liquid manure spreader
(3) <u>5.8%</u> Lagoon
(4) <u>0.3%</u> Oxidation ditch
(5) <u>5.0%</u> Combination of above
(6) <u>4.9%</u> Natural drainage

production facilities, and waste management practices. The survey forms were mailed to county extension chairmen under a cover letter by the Director of the North Carolina Agricultural Extension Service and a 100 percent response occurred. Original data on number of units in each system for specified herd sizes was extrapolated to indicate the number of hogs for each system type according to herd size using the average for each size interval as the weighting factor, Table 7. Results of this data expansion to determine number of hogs grown in each production system resulted in some discrepancies because some producers have more than one unit and thus are included under several system types; i.e., the total number of producers in the state is 21,451 whereas there are 24,649 different units. These differences were not considered significant. The fraction of total hogs produced in the three typical housing units based upon 2,818,806 total hogs was 28 percent on solid floors (System 1, 2 and 5); 31 percent on slatted floors (System 3 and 4); and 41 percent produced on pasture and drylot (System 6 and 7). A further refinement shows that 34 percent of all hogs are produced in dirt lots and 7 percent on pasture. On a unit basis using the total number of units (24,649) rather than producers (21,451), the percent in each housing category are: solid floors - 13 percent, slatted floors - 7 percent, pasture - 23 percent, and dirt lots - 57 percent. Therefore, on a total hog basis, industry structure in North Carolina is approximately: solid floor facilities - 30 percent, slatted floors - 30 percent, and pasture or drylot - 40 percent; and on a unit basis: solid floor - 13 percent, slatted floors - 7 percent, and pasture or drylot - 80 percent. Obviously, pasture or drylot units are most numerous but generally smaller operations and slatted floor units are most common for the large, totally enclosed units. This is consistent with the fact that North Carolina leads the nation in production units for over 1,000 hogs and most of these new units are environmentally controlled with underfloor ventilation systems.

National Evaluation-

A recent report "Implications of EPA Proposed Regulations of November 20, 1975, for the Animal Feeding Industry," was developed to provide analyses of proposed regulations to help insure that regulations represent a balance between control and adverse impacts on the animal feeding industries (USDA 1976). Data for this USDA report were not based on a survey of animal feeding operations, but represented judgement of experts in major livestock and poultry producing states. These states account for 90 percent of hog and pig marketing in the United States.

Concentrated animal feeding operations that would come under the proposed EPA criteria were determined according to any one of three criteria:

Table 7. SWINE INDUSTRY FOR NORTH CAROLINA, 1974

Total number of swine in state: 2,865,860Total number of producers in state: 21,451

Waste Management System	Herd Size (In One Operating Unit)						Totals
	1 to 24	25 to 99	100 to 299	300 to 499	500 to 999	1,000 to 2,499	
1. Solid floor & storage tank (units)	3	16	16	12	7	1	55
Total number of swine	36	800	3,200	4,800	5,250	1,750	15,836
Percent of total (unit basis)	5.4	28.6	28.6	21.3	12.5	3.6	100
Percent of total (hog basis)	0.2	5.0	20.2	30.3	33.2	11.1	100
2. Solid floor and lagoon (units)	94	439	832	417	195	67	2,044
Total number of swine	1,128	21,950	166,400	166,800	146,250	117,250	619,778
Percent of total (unit basis)	4.6	21.5	40.7	20.4	9.5	3.3	100
Percent of total (hog basis)	0.2	3.5	26.8	26.9	23.6	18.9	100
3. Slatted floor & lagoon (units)	63	228	282	416	370	179	1,638
Total number of swine	756	11,400	56,400	166,400	277,500	313,250	825,706
Percent of total (unit basis)	4.1	14.8	18.3	27.1	24.1	11.6	100
Percent of total (hog basis)	0.1	1.4	6.8	20.2	33.6	37.9	100
4. Slatted fl/w direct spreading	14	4	31	31	15	6	101
Total number of swine	168	200	6,200	12,400	11,250	10,500	40,718
Percent of total (unit basis)	15.4	4.4	34.0	23.1	16.5	6.6	100
Percent of total (hog basis)	0.4	0.5	15.2	30.5	27.6	25.8	100
5. Solid fl/w direct spreading (units)	348	379	229	157	18	2	1,133
Total number of swine	4,176	18,950	45,800	62,800	13,500	3,500	148,726
Percent of total (unit basis)	30.7	33.5	20.2	13.8	1.6	0.2	100
Percent of total (hog basis)	2.8	12.7	30.8	42.2	9.1	2.4	100
6. Dirt lot (units)	8,315	3,813	1,433	332	154	72	14,129
Total number of swine	99,780	190,650	288,600	132,800	115,500	126,000	953,330
Percent of total (unit basis)	28.9	27.0	10.2	2.3	1.1	0.5	100
Percent of total (hog basis)	10.5	20.0	30.3	13.9	12.1	13.2	100
7. Pasture lot (units)	3,901	1,313	385	35	15	--	5,649
Total number of swine	46,812	65,650	77,000	14,000	11,250	--	214,712
Percent of total (unit basis)	69.1	23.2	6.8	0.6	0.3	--	100
Percent of total (hog basis)	21.8	30.6	35.9	6.5	5.2	--	100
Total (unit basis)	12,738	6,192	3,218	1,400	774	327	24,649
Total (hog basis)	152,856	309,600	643,600	560,000	580,500	572,250	2,816,806
Percent of total (unit basis)	51.7	25.1	13.1	5.7	3.1	1.3	100
Percent of total (hog basis)	5.4	11.0	22.8	20.0	20.6	20.3	100

1) operations that have a man-made waste conveyance that discharges to navigable water, 2) measurable waste discharges directly into navigable water originating off-site and traversing the production unit, and 3) runoff from less than the 25-year, 24-hour storms for operations of 1,000 animal units or more. The estimated number of swine production sites considered to be concentrated animal feeding operations under these criteria are 48,470, Table 8.

If only the 25-year, 24-hour storm criteria were applied to all units regardless of size, 54,580 units would be effected, Table 8. The total number of animal feeding units to be considered as concentrated animal feeding operations under the conveyance, navigable water and total implementation of the runoff criteria regardless of unit size are thus the addition of the two separate groups in Table 8 or 103,050, which is about 25 percent of all operations.

Most of the 54,580 producers throughout the United States that would be affected by runoff criteria probably have unroofed facilities such as drylots and concrete pad units. Assuming all of the 14,129 dirt lots in North Carolina would come under the case-by-case rainfall runoff criteria, then a comparison of these two data sources indicates that about 25 percent of all units impacted by the rainfall criteria are in North Carolina. Although all drylots throughout the United States may not require retention of runoff from less than a 25-year, 24-hour storm because of differing management techniques and geoclimatic conditions, it is most improbable that all of these units are in the Southeast, based on linear extrapolation of North Carolina data through a similar production and geoclimatic region. The discrepancy among various data sources available for assessing how swine are raised or which systems have environmental consequences is not presently resolved.

In summary, it appears that the total economic and technical impact of proposed EPA criteria on existing swine production units is not fully understood, nor well documented. Therefore, the need for better characterization of the swine industry and more research on runoff transport, discharge definition, and impact on receiving streams in light of associated economic and technical considerations is emphasized.

Trivia

The center of the United States hog population was calculated using standard center of population techniques. For the years 1974 and 1975, the hog center was along the La Moine River between Brooklyn and Colmar, Illinois. The population center moved northwest from near Brooklyn in 1974 to near Colmar in 1975.

Table 8. IMPACT OF EPA CRITERIA ON SWINE INDUSTRY IN MAJOR LIVESTOCK PRODUCING STATES (USDA 1976).

Swine Industry	Operating capacity (in animal units) 2/				
	Less than 100	100- 199	200- 299	300- 999	1,000 and over
Estimated number of operations in major livestock producing states	252,800	104,600	40,200	8,500	4,200
Discharge and runoff control for operations with more than 1,000 animal units	31,330	11,800	4,240	760	330
Runoff control only for all units regardless of size	34,840 14%	13,890 13%	4,850 12%	1,000 12%	-
Percent of all operations					54,580 13%
Discharge and runoff control for all units regardless of size	66,170 26%	25,690 25%	9,100 23%	1,760 21%	330 8%
Percent of all operations					103,050 25%

SECTION V

PROPERTIES OF SWINE WASTE AND PRODUCTION UNIT WASTE LOAD

The waste load produced at any swine growing unit has a single common basis which is derived simply from the magnitude of animals present, expressed in total liveweight. In general, it is this common waste load, hereafter called the defecated or raw waste load, which must be considered in the utilization, disposal, or treatment of swine waste.

Different swine production units provide various levels of storage and pretreatment prior to the conveyance of the raw waste defecated by the hog from the production unit. The waste load from a production unit is defined herein as that waste material leaving the area or building in which the hogs are produced. With this definition, it should be theoretically possible to compare the waste from the several types of production units to the raw waste to determine the magnitude or percentage of alteration. As a convenient descriptive assumption, pretreatment unit processes physically located in the production unit are characterized as following the housing facility and are discussed in a later section. This choice is arbitrary, but does provide a clear delineation between production unit waste load and evaluation of the many uniquely different disposal, pretreatment, or utilization schemes extramural to the production unit.

The chemical concentrations used in characterization of swine waste were either mass of a species per unit volume of total waste (mg/l) or mass of a species per unit mass of total dry solids (ppm or %). Bacterial densities were reported as numbers per 100 ml of swine waste. The generation rate was expressed as the mass of a species produced per day per 45-kg hog (100 lb). This rate is the anticipated waste load for a 45-kg hog and data for other average weights were corrected by the appropriate weight ratio. The generation rate was not the waste load per 45-kg of liveweight gain since that would vary depending on the initial weight. The relationship between data presented in this report and relevant housing units is detailed in Figure 10.

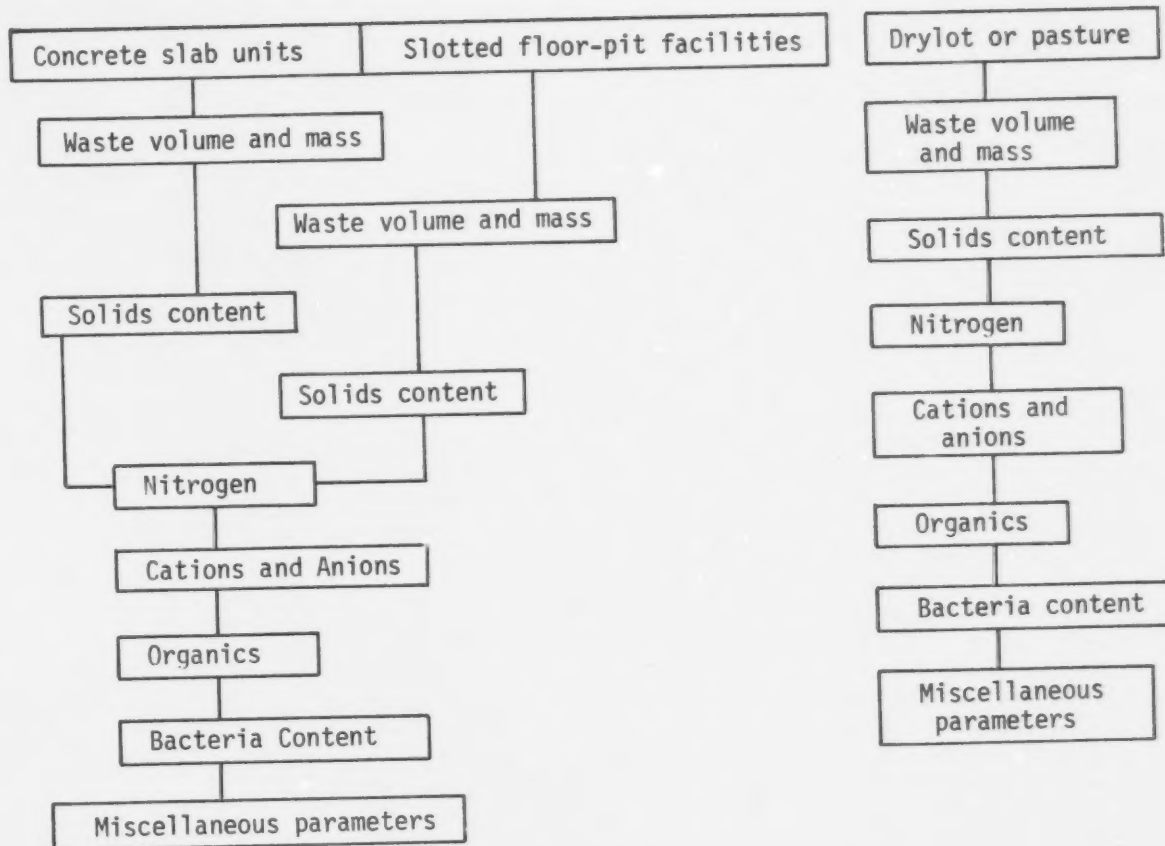


Figure 10. Flow chart for data presentation of waste load from swine production unit categories.

CONCRETE SLAB AND SLOTTED FLOOR-PIT SWINE WASTE LOADS

The properties of defecated swine waste are affected by a multiplicity of factors which determine the very being of an animal. A number of qualitative and basic nutritional or physiological discussions are available which document waste determining factors (Morrison 1959). Limited data exist for effects of controlled environment housing, hog activity and correspondingly volume and ratio of feed and water consumed. Basic studies of defecated waste are useful in defining relationships between waste constituents and physiologic factors.

Type and Size of Animal

Waste quantity and quality data reported for different types and sizes of hogs (Irgens 1965, Muehling 1971, Day 1969, and ASAE 1972) are presented in Tables 9, 10, 11 and 12. Swine age, when normalized on a per kg of animal weight basis, does not appear to significantly influence the amount or chemical content as reflected in the BOD_5 of the raw waste. Gestating sows and boars appear to produce a lower BOD_5 based upon kg BOD/kg animal and thus may have a slightly lower environmental impact. In terms of total national swine production, about 15 percent are boars and gestating sows.

In all subsequent discussion, the waste loads are grouped (within the limits of literature clarity) according to the three main classes of production units: 1) concrete slab, 2) slotted floor over pits, and 3) swine drylot or pasture, Table 13. It is intended that only experimentally measured values are listed in the raw waste summaries. These data have been distilled and collected from articles listed in the reference section and from a search of the conference proceedings listed. A partial list of workers who have used or summarized original data in, or who have made additional estimates and allowances for, particular management methods areas follows: Spillman 1960, Morris 1961 and 1971, Linn 1973, Willrich 1966, Midwest Plan Service 1966, McKinney 1967, Muehling 1969, Laak 1970, Fogg 1975, Loehr 1968, Okey 1971, Windt 1971, ASAE 1972, Pork Producers 1972, and Bruns 1975.

Waste Volume and Mass - Concrete Slab Units

The predominance of data for concrete-slab units was for feces and urine which were scraped or water-washed into a side gutter or sump. The frequency of waste collection was usually daily or at the most within 48 hours. From an independent poll by the National Pork Producers Council and North Carolina State University, the usual producer scraping frequency is 2-4 times per week; hence, literature data for nonconservative elements may be higher than actual producer waste loads.

Table 9. MANURE PRODUCTION OF GROWING AND FINISHING PIGS (IRGEN 1965)

Pig Weight (kg)	Age (Weeks)	Feces -----kg/day/kg of animal-----	Urine -----kg/day/kg of animal-----	Total -----	Total Volume Liters
5.5 - 18	3 - 8	0.027	0.058	0.085	0.038
18 - 36	8 - 12	0.043	0.048	0.091	0.041
36 - 54	12 - 16	0.054	0.061	0.115	0.050
54 - 72	16 - 20	0.046	0.058	0.104	0.047
72 - 90	20 - 23	0.047	0.051	0.098	0.044

Table 10. APPROXIMATE DAILY MANURE PRODUCTION (MEDIAN VALUES FOR UNDILUTED MANURE WITHOUT BEDDING) (MIDWEST PLAN SERVICE 1969)

Age (Weeks)	Weight (kg)	Liquids and Solids		Wet Solids Only	
		Liter	Liter/kg of animal	kg	kg/kg of Animal
Pigs					
6 - 9	18	1.9	0.100	1.1	0.060
9 - 13	45	3.8	0.082	2.7	0.059
13 - 18	68	6.5	0.093	4.0	0.059
18 - 23	95	8.4	0.087	5.5	0.057
Sows, Boars					
20 - 52	135	11.0	0.082	8.0	0.058
52+	225	18.8	0.082	13.6	0.060
Sow + Litter ..		15.0		13.6	

Table 11. RAW WASTE LOAD GENERATED FOR DIFFERENT TYPE OF SWINE (Day 1969)

Animal	Weight/Animal kg	BOD ₅ kg/day/animal	BOD ₅ kg/day/kg of animal
Boar	160	0.18	0.00114
Gestating Sow	125	0.18	0.00145
Sow with Litter	170	0.34	0.00200
Nursery Pig	16	0.03	0.00200
Growing Pig	30	0.06	0.00200
Finishing Pig	68	0.14	0.00200

Table 13. PRODUCTION UNITS REPRESENTED IN THREE CATEGORIES OF FACILITIES DELINEATED IN STATE-OF-THE-ART REPORT

Report Category	Common Production Facility
Concrete Slab	Side curtain totally roofed concrete floor building
	Partially roofed, high density concrete slab system
	Minimally shaded concrete slab facilities
Slatted Floor-Pit	Partially slotted confined housing
	Totally slotted floor units
	Slotted floor units with environmental regulation and ventilation
Drylot	Dirt lot with shaded feeders
	Pasture production

Table 12. ASAE FACT SHEET 1972, AW-D-1, FRESH MANURE (FECES AND URINE)
PRODUCTION AND CHARACTERISTICS PER 450 kg LIVE WEIGHT

Characteristic	Units	Swine	
		Feeder	Breeder
Raw Manure	kg/day	34.000	23.0
Volume	liters	34.000	23.0
Total Solids	kg/day	13.000	9.5
	% of raw manure	8.000	8.6
Volatile Solids	kg/day	10.600	7.0
	% of total solids	80.000	75.0
BOD ₅	kg/day	4.400	2.9
	% of total solids	33.000	30.0
COD	kg/day	2.600	2.4
	% of total solids	95.000	90.0
Nitrogen	kg/day as N	0.230	--
	% of total solids	8.300	
Phosphorus	kg/day as P	0.068	--
	% of total solids	2.500	
Potassium	kg/day as K	0.140	--
	% of total solids	5.000	

Characterization values were not consistently reported either as waste volume (liters, l) or mass (kilogram, kg); hence, a conversion factor, swine waste density (kg/l), was needed to obtain greater data commonality. A determination was made of swine waste density over the range of 1.3 to 17.8 percent solids, Table 14. A unity conversion factor between kilograms and liters was selected as representative and within the precision of subsequent literature references. Using this factor to expand the data base, the total waste load from concrete slab unit, Table 15, was determined, for minimal excess water use to be 3.4 kg/d and 3.4 l/d per 45-kg hog. Larger values, reported up to 38 l/d/45-kg hog, are accurate and simply reflect the water use typical of leaky waterers, low pressure hose washing, or excess summer mist cooling. The effect of such excess water is simply to dilute defecated waste and proportionally increase the required waste handling and transportation. The dependence of research data on the amount of excess process water is responsible for the high variability of total waste volume data. This variability is also present in producer facilities and is an important management option which can be directly controlled to reduce waste handling costs.

Waste Volume and Mass - Slotted Floor-Pit Facilities

For a partial or totally slotted floor unit with manure pits, literature values for daily swine waste volume and mass were tabulated, Table 15. As with concrete slab facility data, there were high waste volume values indicating excess water usage. The characteristic swine waste volume and mass was determined to be 4.1 l/d/45-kg hog and 4.1 kg/d/45-kg hog which is slightly higher than the concrete slab unit possibly because of the small data base available for concrete slab facilities.

Because of the strong influence of water-related equipment condition and cleaning techniques, the possible differences between concrete slab and slotted floor units were not judged significant. Including the data from unspecified housing units, Table 15, the swine waste volume representative of minimum excess water usage was 3.8 l/d/45-kg hog ranging up to 40 l/d/45-kg hog for high water usage in cleaning, flushing or malfunctioning waterers and foggers. The corresponding wet manure plus urine mass was 3.8 kg/d/45-kg hog at minimum water input.

The waste volumes of 2.4 kg/d/45-kg hog was recommended (Taiganides 1964) as the solid waste amount after excess liquid was drained. That is, the amount to be handled in solid form. When calculating the solids as a percent of the average total waste volume, the solids-only data correlates well with literature references which report the ratio of feces to total waste mass as 45-70 percent, Table 15.

Table 14. DENSITY OF ANIMAL WASTE SLURRIES (OVERCASH 1972, 1973)

Waste Type	Percent Solids	Density, g/ml
Swine	0.13	0.9970
Swine	0.65	1.0070
Swine	1.30	1.0100
Swine	2.70	1.0160
Swine	3.60	1.0043
Swine	8.20	1.0210
Swine	17.80	1.0500
Poultry	13.30	0.9800

Table 15. SWINE WASTE GENERATION-VOLUME AND MASS

	Volume, l/d/45-kg hog	Mass, kg/d/45-kg hog	Feces % of total waste mass
<u>Concrete slab facilities</u> <u>(1-3 day holding times)</u>			
Converse 1970	--	5.2	
Humenik 1972	42.0	42.0	
Jones 1972	4.9	4.9	
Loynachen 1974	7.6	7.6	
Ngoddy 1971 (metabolic cages)	2.3	2.3	
Overcash 1972	9.5	9.5	
Schmid 1969	3.4	3.4	
Talpanides 1964 (solid fraction)	2.3	2.3	
Value judged most reliable	3.4	3.4	
<u>Slotted floor-pit systems</u>			
Evans 1975 (Scotland)	14.0	14.0	
Hepherd 1975	4.5	4.5	
Ingen 1965	1.5	1.5	44
Kesler 1966	4.2	4.2	
Koch 1975	5.7	5.7	
Maddex 1975	5.7	5.7	
Overcash 1973	4.5	4.5	
Pontin 1968 (finishing hog)	7.9	7.9	
(sow)	9.5	9.5	
Scheltzinger 1966	3.1	3.1	
Sewell 1973 (waterer input)	5.3	5.3	
Value judged most reliable	4.2	4.2	
<u>Unspecified confinement housing</u>			
Baines 1964	11-22	11-22	
Davis 1969	--	--	65
Geldreich 1962	4.2	4.2	
Hobson 1973	4.9	4.9	
Lane 1975	5.7	5.7	
Lynn 1968	--	--	63
Muehling 1969	3.8	3.8	71
Scholtz 1971	3.6	3.6	
Webber 1968	3.8	3.8	

Solids Content (Total, Volatile, Suspended, and Volatile Suspended):
Concrete Slab Unit

The daily total solids (TS) and ratio of volatile solids (VS) to total solids are frequently documented in waste generation and pretreatment research studies, Table 16. The reported concentrations of TS and other parameters were found to depend somewhat on feeding technique (Willrich 1966). Floor feeding does not make excess feed available as does self-feeding operations. Hogs clean up the floor and less feed becomes part of the production unit waste load. A reduction in the waste load from 0.3 to 0.2 kg VS/day/45-kg hog was reported in association with conversion from self-feed to floor feeding. However, a confounding factor can be the variability and test differences associated with the analytical method employed (Prakasam 1975).

In review of the available data, Table 16, there was good consistency in the total solids waste load, especially in comparison to the variability of the total production unit waste amount. The value judged most reliable was 0.27 kg TS/d for a 45-kg hog.

The ratio of volatile solids (VS) to total solids (TS) was a frequently measured parameter, Table 16. The VS/TS ratio judged most reliable was 0.79 for manure plus urine as the total waste. A higher ratio of 0.84 appeared to better characterize the feces or solids-only values. Hence, where refinements in waste process design are needed, the appropriate VS/TS ratio should be used for manure plus urine or for manure solids only. The amount of VS generated from a concrete slab unit was determined to be 0.21 kg VS/d/45-kg hog, Table 16.

Solids Content (Total, Volatile, Suspended, and Volatile Suspended):
Slotted Floor-Pit Facilities

Data from slotted floor facilities were not as abundant, Table 16. The range in the four values for total solids was from 0.12 to 0.25 kg TS/d/45-kg hog.

Although the data base for total solids from slotted floor units was not large, the range and average values were about 25 percent below the results from concrete slab units. The average annual generation rate was determined to be 0.20 kg TS/d/45-kg hog.

There are a priori reasons for differences between concrete slab and slotted floor facilities, such as detention time on floor, exposure to sun and wind, decomposition during pit storage, etc. However, the literature data suggest that resulting differences are not great (i.e. less than 30 percent) in comparison to the levels of detection inherent in field measurements and that a single value can be used.

Table 16. SWINE WASTE GENERATION - TOTAL (TS) AND VOLATILE SOLIDS (VS)

	VS kg/d/45-kg hog	VS kg/d/45-kg hog	VS/TS
<u>Concrete slab facilities</u> (1-3 day holding times)			
Barth 1975 (solids only)	--	--	0.85
Clark 1965	0.23	0.18	0.79
Converse 1970	0.25	0.20	0.81
Grammes 1971 (feces-24 hrs.)	--	--	0.83
Humenik 1972	0.26	0.21	0.83
Humenik 1972 (feces)	--	0.21	0.81
Jett 1973 (feces-48 hrs.)	--	--	0.86
James 1972	0.30	0.23	0.77
Lomachen 1972	--	--	0.77
Ngoddy 1971 (metabolic cage, 80 percent feces, 20 percent urine)	0.23	0.18	0.83
Scheid 1969	0.27	0.21	0.80
Tatjanides 1964 (solids only)	0.34	0.25-0.30	0.74-0.84
Willrich 1966	--	0.19	--
Value judged most reliable	0.27	0.21	0.79
<u>Slatted floor-pit systems</u>			
Fong 1973	--	--	0.85
Hepherd 1975	0.24	--	--
Irgen 1965	0.12	0.10	0.88
Kesler 1966	0.25	--	--
Overcash 1973	0.20	0.15	0.78
Value judged most reliable	0.20	0.11-0.16	0.80
<u>Unspecified confinement housing</u>			
Benne 1961	--	--	0.80
Collins 1975	--	--	0.89
Fischer 1975	--	--	0.85
Hart 1965	0.36	0.28	0.78
Hobson 1973	0.86	--	--
Holland 1975 (feces)	--	--	0.85
Jeffrey 1965	--	--	0.87
Lynn 1968	--	--	0.79
Pearce 1975 (feces)	--	--	0.82
Robinson 1966 (feces)	--	--	0.84
Scholz 1971	0.36	--	--
Spillman 1960	--	--	0.85

The volatile solids generation was judged to be lower for the slotted floor-pit facility 0.13 kg VS/d/45-kg hog, although there were only two data points. The volatile to total solids ratio was about 0.83. Thus, refinements in VS and TS loads could be applied to different production units as needed.

Absorbing the 25 percent variation for different production units and the data from unspecified housing facilities, Table 16, the rates of 0.18 kg VS/d/45-kg hog and VS/TS equal to 0.81 were chosen as representative of swine waste from slotted and concrete slab units. The relatively high VS and TS values reported over 15 years ago (Taiganides 1969) were acknowledged to represent earlier feed rations and management practices.

Conversion of TS and VS and waste volume generation from Tables 15 and 16 into production unit waste concentrations yields approximately 70,000 mg TS/l and 55,000 mg VS/l. The corresponding raw waste moisture content is 93 percent. Larger waste volume due to excess water input would produce a proportional dilutional effect on these solids concentrations.

Limited data are available for total suspended solids (TSS) and volatile suspended solids (VSS), Table 17. For reported data (Yagi 1975 and Collins 1975a) which were expressed as a percent of TS, the average value of 0.27 kg TS/d/45-kg hog was used to calculate the total suspended solids generation. The TSS and VSS values judged most reliable were 0.19 and 0.15 kg/d/45-kg hog, respectively. Calculated raw waste concentrations were thus 50,000 mg TSS/l and 40,000 mg VSS/l.

Nitrogen

The forms of nitrogen present in swine waste are organic (O-N) and ammonia nitrogen ($\text{NH}_3\text{-N}$). The total Kjeldahl nitrogen (TKN) is the sum of these two nitrogen forms with the exception of certain more resistant compounds which are not detected by this procedure (Standard Methods 1971). Constituents not detected by the TKN analysis are not present at significant levels in swine waste. Literature data for nitrogen generation from a concrete slab facility, Table 18, are somewhat more variable than those for TS. The average generation rate is 0.018 kg/d/45-kg hog. Also tabulated in Table 18 are data for nitrogen amounts from a slotted floor-pit facility for which the average value is 0.018 kg/d/45-kg hog. Finally, a number of references were found in which the production unit was unspecified, Table 18.

Table 17. SWINE WASTE GENERATION-TOTAL SUSPENDED SOLIDS (TSS) AND VOLATILE SUSPENDED SOLIDS (VSS)

Concrete slab and slotted floor-pit facilities	TSS kg/d/45-kg hog	VSS kg/d/45-kg hog
Collins 1975 (using 0.27 kg TS/d/45-kg hog)	0.15	0.13
Converse 1970	0.20	0.17
Davis 1969	0.20	--
Evans 1975	0.20	--
Hobson 1973	0.86	--
Jones 1972	0.17	--
Pontin 1968	0.15	--
Schmid 1969	0.21	--
Yagi 1975	0.21	--
Value judged most reliable	0.19	0.15

Table 18. SWINE WASTE GENERATION AND DRY MATTER COMPOSITION-NITROGEN

	N g/d/45-kg hog	N Percent TS	NH ₃ -N/TKN
<u>Concrete slab facilities</u> (1-3 day holding times)			
Barth 1975 (solids only)	9	3.4	--
Clark 1965	--	--	0.42
Converse 1970	8	3.3	--
Grams 1971	10	3.8	0.21
Jett 1973 (feces)	9	3.3	--
Jones 1972	26	--	0.41
Loynachen 1972	12	4.4	--
Negulescu 1975	18	--	--
Ngoddy 1971 (metabolic cages-80% feces, 20% urine)	16	10.0	0.49
Overcash 1972	23	7.3	--
Scheltz 1966	22	--	0.93
Talantides 1964 (solids only)	24	7	--
Willrich 1966	18-32	--	--
Value judged most reliable	18	6.5	0.5
<u>Slotted floor-pit systems</u>			
Evans 1975	26	--	0.53
Fong 1973	--	4.5	0.21
Hepherd 1975	11	--	--
Irgen 1965	10	--	--
Kesler 1966	24	9.3	--
Osaway 1975	--	4.4	--
Overcash 1973	18	9.8	0.44
Value judged most reliable	18	7	0.4
<u>Unspecified confinement housing</u>			
Baldwin 1975	--	3.0	--
Benne 1961	9	--	--
Clawson 1974 (feces)	--	4.0	--
Davis 1969	10	--	--
Hart 1965	14	4	0.74
Holland 1975 (feces)	--	3.8	--
Kornegay 1975	--	3.7	--
Lane 1975	38	--	--
Moore 1969	23	--	--
Orr 1971 (feces)	--	3.4	--
Pearce 1975 (feces)	--	3.0	--
Poelma 1966	32	--	--
Robinson 1966 (feces)	--	2.7	--
Spillman 1960	--	6.1	0.48
Stevenson 1975	--	3.4-4.1	--
Stevenson 1974	31	--	--
Webber 1968	26	6.6	--
Yagi 1975	--	8.8	0.45
Value judged most reliable for all confinement housing units	18	6.5	0.5

The evaluation of the relative advantages of slotted floor or concrete slab units for nitrogen losses or conservation is limited because of incomplete documentation of the total defecated amount, the severe restrictions of sample storage and analysis (Overcash 1975a, Moore 1975, and Humenik 1975) and the variability of field sampling (Reddell 1975). Two authors (Clawson 1974 and Stevermer 1975) using a specific ration and carcass value determined by difference that the nitrogen excreted was 0.031 kg/d/45-kg hog. Few values this high appear in Table 18, and as shown in a later section, similar theoretical calculations for conservative elements, phosphorus and potassium, were above average measured values by 150 to 180 percent. Therefore, data inconsistencies exist in establishing the excreted nitrogen load.

As an approximation of housing unit effect on waste nitrogen, one may assume that the consistent upper values of 0.023 to 0.027 kg/d/45-kg hog in Table 18 represent the defecated waste load. Thus in comparison, the waste load from the concrete slab and slotted floor with storage pit units is reduced by 20 percent-30 percent. Neither unit appears to have a disproportionately greater nitrogen waste load. Alternatively, a more realistic estimate of waste load may be the average of all data or 0.018 kg/d/45-kg hog. Further evidence of the expected low TKN losses for manure pit conditions was presented in a study of room temperature storage losses (Moore 1975). Less than 10 percent loss of TKN was found after 4 weeks.

Another study (Lauer 1975) under controlled conditions showed 10-30 percent nitrogen loss for exposed dairy waste after one day. It would be expected that when wastes are stored in tanks or pits below slotted floors the nitrogen volatilization losses would be reduced below that for wastes on a concrete floor exposed to weather conditions for 1-3 days. Literature data are variable and do not show such a trend. Quite possibly substantial nitrogen losses may occur rapidly before manure is forced through slots to the pit so that similar nitrogen losses occur in both production units. Again, in lieu of a more precise definition, the approximate values in Table 18 can be used and possibly supplemented by actual waste analyses.

The waste fraction which is in the ammonia form ($\text{NH}_3\text{-N}$) showed considerable variation, Table 18. Demonstrated rapid changes in sample ammonia concentrations (Moore 1975) even under refrigerated conditions would account for the $\text{NH}_3\text{-N}$ /TKN variability. An average value of 0.50 as the ratio of $\text{NH}_3\text{-N}$ /TKN was adopted.

With the daily generation rate of TKN, TS, and total waste volume, several average concentrations can be calculated. The nitrogen, as a percent of the solid dry matter, was 7.8 percent. Recorded

values in Table 18 (many for feces only) were generally 50-60 percent of this value. One possible explanation could be that since much of the nitrogen is ammonia, storage or drying losses were substantial. For minimum water use, raw swine waste concentrations were approximately 5,500 mg N/l for 3.8 l waste volume/d/45-kg hog.

In summary, the percentage loss of nitrogen in the material leaving concrete slab or slotted floor production units could not be accurately estimated because of insufficient data. The waste load from concrete slab and from slotted floor-pit units was not substantially different. A similar conclusion for nitrogen, phosphorus and potassium was reached for a detailed comparison of beef wastes in slotted floor-pit and totally-roofed, concrete slab units (Adriano 1975). The relationship of these production unit waste loads could not be compared to the defecated waste because of lack of defecated waste data.

Cations and Anions Expressed as Elements

There are a number of conservative constituents in swine waste which present an environmental impact, sometimes as the land limiting components. This impact is often categorized as: 1) salt content or salinity or 2) potentially toxic heavy metals. The cations and anions in this category are conservative and thus the defecated amounts are equal to the amounts leaving the production unit and reaching the pretreatment process (excepting the miniscule amounts necessary for microbial biomass).

There are several discussions of the toxic and salinity effects of wastes applied to land or accumulating in biological waste treatment systems (Stewart 1976, Bomke 1975, Horton 1975, Loehr 1973). With respect to land application, swine waste is very concentrated when expressed as mg of various ions per liter of waste. However, the critical factor in the plant-soil system is the total mass of various constituents applied annually and the volume of dilution water from rainfall. That is, the plant-soil receiver has a capacity for a large variety of salts, ions, and elements; and the concentration of application is less important in the long term than the actual mass applied. This is not true for many water-based treatment systems in which peak concentrations represent potentially deleterious shock loads. Hence, it is important to document the generation rate, as well as the concentrations of various conservative constituents.

The format for literature reporting is usually mg/gTS, mg/l of waste, or g/d/45-kg hog. Predominantly, the amount of an element per unit of total dry solids is used. Additionally, some researchers have given detailed feces analyses. Data for feces (expressed as a percent

of TS) can be used to represent the entire waste load if the contribution from urine is small. That is, certain constituent analyses are urine sensitive. In a detailed reporting (Ngoddy 1971) of the feces and urine fractions of swine waste, it was determined that potassium (K), sodium (Na), and possibly sulfur (S) analyses expressed per unit of total solids are strongly dependent on urine content. For the parameters phosphorus (P), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn), the feces and total waste values expressed as mass per unit of dry solids are nearly equal. Thus, feces data can be used directly for these elements. Using the chelation bonding strength relations proposed and demonstrated for swine waste lagoon pretreatment (Overcash 1976b), the elements cadmium (Cd) and cobalt (Co) are projected to be urine insensitive. It is unclear whether this would be true for lead (Pb), molybdenum (Mo) and aluminum (Al), but the assumption of feces analysis equating to total waste analysis is necessarily made due to lack of urine data.

The ratio of individual elements to total dry solids (expressed as ppm or percent) are tabulated in Table 19 for feces plus urine, feces only, and those data which were unspecified as to housing unit. For those parameters which were urine insensitive or where there were few data, a single value judged most reliable is given, Table 19. For phosphorus, potassium and sodium, a value was determined for feces only and for the feces plus urine data, Table 19.

The sodium and potassium amounts per unit of total dry solids were found to be consistently lower for feces only, Table 19, indicating the need for extra caution in collecting swine waste samples and for interpreting literature values. Phosphorus, one of the urine insensitive parameters, was similar in concentration for the average of the feces plus urine and for feces only. Thus, total waste, manure solids, or feces data can be used for the urine insensitive parameters.

Evaluation of parameter generation rate in Table 20 involves: 1) the concentration determination per unit of waste volume or per unit of total solids and 2) a measure of daily waste volume or solids production. Several literature evaluations, Table 20, were found for phosphorus and potassium, while only limited data were available for other parameters. Therefore, an additional entry using the waste concentration from Table 19 and the average total solids rate (0.23 kgTS/d/45-kg hog) was included for all parameters, Table 20. The summary of all available data was included in Table 20 to give the daily output of these elements per 45-kg hog.

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Table 20. SWINE WASTE GENERATION AND LIQUID CONCENTRATION - CATIONS AND ANIONS EXPRESSED AS ELEMENTS AS ELEMENTS

	P	K	Ca	Mg	Na	Fe	Zn	Cu	Cu dry elec-	Mn	B	Cl	S	Cd	Al	Co	Ni	Pb
									dry Cu level		g/45-lb hog							
Concrete slab and limited floor-pit housing unit																		
Converse 1970	5.5	3.5																
Davis 1969	3.9																	
Hart 1965	2.5	5.																
Howard 1975	4.5	8.2	5.5	1.8	1.4													
Hummels 1972																		
Iryon 1965	7.7						0.16			0.25								
Jones 1972	7.3																	
Kessler 1966	2.0	4.3																
Lew 1975	9.1	6.4	17.3	2.4	0.82	0.10	0.045			0.15		4.4						
Muom 1969	3.2	11.4																
Ngoddy 1971	8.2	7.7	5.5	2.7	1.4	0.11	0.11		0.11	0.045								
Overcash 1976	6.8	5.9	5	1.7	2.3	0.086			0.16	0.05								
Stevenson 1974 (theoretical calculation)	16	11.4																
Tesquedon 1964 (collon only)	4.1	15	12.3	1.7	0.6	0.13	0.034			0.09		3.1						
Wabber 1968	6.4	1.3																
Wittlich 1966	5.9	11.4-22.8																
Composite using average TS generation and dry matter composition (Tables 16 and 15)	5.9	7.3	9.1	2.3	2.3	0.45	0.17	0.083	0.27	0.048	0.11	13.6	2.4	0-2.7x10 ⁻⁴	0.15	1.6x10 ⁻³	0-9x10 ⁻⁵	3.2x10 ⁻³
Value judged most reliable, 9/4/65-kg hog	5.9	8.2	9.1	2.3	2.3	0.46	0.14	0.023	0.18	0.066	0.11	13.6	3.2	0-2.7x10 ⁻⁴	0.18	1.6x10 ⁻³	0-9x10 ⁻⁵	3.2x10 ⁻³
Liquid concentration calculated on basis of 3.8 1/4/65-kg hog, ml/l	1,500	2,200	2,420	600	600	120	35	6	50	15	0.3	3,500	860	0-0.1	36	0.5	0-0.005	0.8

For comparative purposes, the waste generation rates judged most reliable were converted to concentration values based on the total swine waste volume. The value of 3.8 l/d/45-kg hog was used with the resultant concentrations expressed as mg/l, Table 20.

In a recent study (Overcash 1976) the production unit mass balance for seven cations (Ca, Mg, K, Na, Cu, Zn, Mn) was evaluated. The study spanned a period of 6 years. Feed amounts were determined, as well as the waste generation from a concrete-slab, fully-roofed swine production unit. The waste as a percentage of feed (carry-over factor) for Cu, Zn, Mn, Ca, Mg, K, and Na was 86 percent, 110 percent, 79 percent, 40 percent, 74 percent, 59 percent, and 66 percent, respectively.

Organic-Related Parameters

The two most widely used measures of the total aggregate of organic compounds in swine waste are the chemical oxygen demand (COD) and the five-day biochemical oxygen demand (BOD₅). A detailed discussion of the techniques and significance of these parameters can be found in several literature sources (Standard Methods 1971, Webber 1973, Arial 1971). In essence, these two analyses approximate the oxidative state of organic compounds by determining the amount of oxygen required to convert waste organics completely to carbon dioxide and water (COD) or the amount of oxygen utilized by microorganisms in a five day period of aerobic oxidation (BOD₅). A third parameter, the total organic carbon (TOC), offers the advantage of determining the actual mass of carbon present in the heterogeneous swine waste mixture. Thus, TOC is approximately the mass of carbon while COD, and BOD₅ approximate the oxidation level of swine waste. Several literature references (Orr 1971 and Miner 1968) were found which detailed some of the individual compounds present in swine waste, but as a rule such specific analyses are not widely performed. Trends toward byproduct recovery will add emphasis to such detailed constituent analyses (Driggers 1976).

Comparison of the COD generation for concrete slab and slotted floor-pit facilities, Table 21, indicates that these waste loads are of a similar magnitude. A recent study (Moore 1975) on storage of raw swine manure at room temperature for four weeks indicated that only 10 percent-15 percent changes in COD and TOC concentrations occurred under these concentrated conditions. Thus, manure pit losses or stabilization of organic constituents are probably not large. The value judged most reliable was 0.30 kg COD/d/45-kg hog. Similar a priori arguments for facility differences and explanations for lack of difference can be made for these organic, nonconservative parameters as were made earlier for nitrogen. The BOD₅ load for all housing

Table 21. SWINE WASTE GENERATION AND DRY MATTER COMPOSITION-ORGANICS

	COD		BOD ₅		TOC	
	kg/d/45-kg hog	STS	kg/d/45-kg hog	STS	kg/d/45-kg hog	STS
Concrete slab and slotted floor-pit housing units						
Barth 1975 (solids)	--	62	--	28	--	--
Clark 1965	--	203	0.19-0.24	25	--	--
Collins 1975	--	89	--	--	--	--
Converse 1970	0.37	--	0.14	--	--	--
Evans 1975	0.35	--	0.17	--	--	--
Fong 1973	--	112	--	--	--	--
Humenik 1972	0.29	110	0.14	50	0.10	36
Irgen 1965	0.20	--	0.08	--	--	--
Jones 1972	0.38	--	0.13	--	--	--
Loymachen 1972	--	--	--	--	--	48
Regulescu 1975	0.24	--	0.10	--	--	--
Ngoddy 1971	0.19	--	0.08	--	--	--
Overcash 1972	0.45	140	--	--	0.09	30
Overcash 1973	0.27	160	--	--	0.07	37
Pontin 1968 (finishing hog)	--	--	0.16	--	--	--
(sow)	--	--	0.17	--	--	--
Scheltzings 1966	0.25	--	0.10	--	--	--
Schmid 1969	0.24	--	0.09 (BOD ₅)	--	--	--
Talpanides 1964 (solids only)	0.33	95	0.14	43	--	--
Willrich 1988	0.32	--	0.13	--	--	--
Unspecified confinement housing						
Baines 1964	--	--	0.11	--	--	--
Collins 1975	--	90	--	--	--	--
Davis 1969	--	--	0.14	--	--	--
Day 1969 (finishing hog)	--	--	0.09	--	--	--
(sow)	--	--	0.07	--	--	--
Fischer 1975 (manure)	--	110	--	--	--	--
Gramm 1971 (feces)	--	101	--	--	--	--
Hart 1965	0.34	--	0.09	--	--	--
Jeffrey 1965	--	136	--	26	--	--
Little 1966	--	--	0.11	--	--	--
Lynn 1968	--	146	--	45	--	--
Poline 1966	--	--	0.10	--	--	--
Webber 1968	--	--	--	--	0.10	--
Yagi 1975	--	--	--	47	--	--
Value judged most reliable	0.30	120	0.12	40	0.09	35

units was 0.12 kg BOD₅/d/45-kg hog. One investigator (Schmid 1969) determined the ultimate BOD to be 0.20 mg/l, Table 21, with the ratio of BOD_u to COD being 0.38. For TOC there were less data available, Table 21. The total mass of organic carbon was determined to be 0.09 kg TOC/d/45-kg hog.

A number of reports also based the COD, BOD₅, and TOC on a percentage of the total dry solids, Table 21. Calculation of these ratio for the average waste generation yielded 130 percent, 50 percent and 40 percent of TS for the COD, BOD₅, and TOC, respectively. The three literature values for the COD/TS ratio for feces or swine solids only were also lower than values for the total waste load as previously noted for urine sensitive constituents. Expressed on a liquid basis for the swine waste volume representative of minimum excess water, 3.8 l/d/45-kg hog, the concentrations for COD, BOD₅, and TOC are 80,000, 32,000 and 24,000 mg/l, respectively.

Bacteria Content

As anticipated, the bacterial concentrations for swine waste were both high and displayed more variability than the chemical parameters, Table 22. The range of values was approximately a hundred-fold for the various bacterial species measured. In addition to quantitative determinations, several qualitative analyses for microorganism present in swine wastes were made, Table 22. To put the bacteria concentrations on the basis of a daily generation rate, the average waste volume (3.8 l/d/45-kg hog) was used, Table 22. These data are, at best, order of magnitude results considering the environmental and sampling factors affecting bacterial decline or death and variations in analytical techniques. Reported data represent semicommercial and research herds, but are applicable to the majority of well managed commercial confinement operations.

Miscellaneous Parameters

Several investigators have measured the volatile acid content and the total alkalinity of swine waste, Table 23. Volatile acids are expressed in terms of equivalents of acetic acid per unit total dry solids. Alkalinity is reported as calcium carbonate equivalents. The average concentrations and generation rates were 50,000 and 6.5 ppm TS and 0.012 and 1.5×10^{-6} kg/d/45-kg hog for volatile acids and alkalinity, respectively.

Table 22. SALINE WASTE GENERATION, LIQUID COMPOSITION, AND PRESENCE OF BACTERIA

All confinement housing units	Total Coliform	Enterococcus group	Enterococcus counts/100 ml (billions)		Aerobes Facilitative group	Enterococcus Salivarius	Streptococcus Bact.	Streptococcus Bact.	Enterococcus Bifidus
			Enterococcus group	Enterococcus counts/100 ml (billions)					
Arl 1970	90	200							
Collins 1970	3.6	40	20	3					
Davis 1969 (Fees)	1	16	860	8,400					
Woods 1962	0.08-1.9	330			15,000	50,000	113,000		
Acorn 1970	1,100	100-1,000	85	10					
Woods 1971	100								
Experiments 1964 (solids only)	1-360	18-1,000	20-1,000	3-8,400	10	100,000	50,000	100,000	
Range of values in order of magnitude value									
Composite generation using 100 ml of waste									
volume and range of bacterial densities, billion counts/dwelling	0.08-13	0.6-36	0.1-200	0.4	4,000	2,000	4,000		

Table 23. SWINE WASTE GENERATION AND DRY MATTER COMPOSITION-MISCELLANEOUS PARAMETERS

All confinement housing units	Alkalinity ppmTS	Volatiles Acids	Crude Fiber	Ether Extract	Crude Protein %TS	Nitrogen Free Extract	Fat	Inorganic Carbon	Gross Energy kcal/g
Barth 1975 (solids only)		2.1							
Bennie 1961		7.8					1.8		
Clark 1965									
Clawson 1974 (feces)		4.8	15.3	10.2	25.1	30.7			2.9
Fong 1973	5.6								
Gramms 1971 (feces)	7.1								
Hart 1965		4.8							
Holland 1975 (feces plus urine)			15	8	23.5	38.3			
Jett 1973 (feces)					20.9	41.4			4.6
Overcash 1973				6.9					2.0
Pearce 1975 (feces)				6.6		29		8	
Robinson 1966 (feces)			18	5.6	17.4				4.3
Feed (Pearce 1975)									5.9
Value judged most reliable	6.5	5	16	8	23	35	1.8	8	4
Composite generation using TS average and average dry matter composition. (Table 16), kg/d/45-kg hog	1.5x10 ⁻⁶	0.012	0.037	0.018	0.053	0.08	0.004	0.018	900 kcal/d/45-kg hog
Liquid concentration (waste volume of 3.8 l/d/45-kg hog), mg/l	0.4	3,200	10,000	4,800	14,000	21,000	1,100	4,800	--

From research on the nutritive value of swine waste, literature references were found for crude fiber, ether extract, crude protein, nitrogen-free extract, and the gross energy (heat of combustion). Except for the gross energy value, the other parameters are expressed as a percent of total dry solids with gross energy reported as kcal per gram of total dry solids. The parameter values judged reliable are listed in Table 23. The average energy value is about one fourth to one third the value of the heat of combustion of most organic compounds (10-13 kcal/g, Perry 1973) indicating the presence of noncombustible reduced compounds. For comparison, parameter concentrations for 17 percent protein feed are also given in Table 23. Conversion of the average parameter expressions on a dry solids basis in Table 23, to a daily generation rate and per unit volume of total waste were accomplished using the average values of 0.23 kg TS/d/45-kg hog and 3.8 l/d/45-kg hog.

Factors Affecting Waste Production

Very few reports were found regarding climatological, management, or housing unit effects, per se. The separation of data in previous sections is a first approximation to differentiate the effect of housing unit. No controlled studies were found which have attempted to evaluate such parameters as nitrogen loss, solids reduction, or organic stabilization of total waste or the urine and feces fractions from different swine housing units. Continued references, however, were found concerning excess water or total waste volume in production facilities.

Feeding Procedure-

Feeding procedures in concrete-floor and partially-slotted units can influence the unit waste load (Willrich 1966). Floor feeding does not make excess feed available as does self-feeding operations. Hence, hogs clean up the floor and less feed becomes part of the production unit waste load. A reduction in the waste load from 0.3 to 0.2 kg VS/day/45-kg hog has been reported with conversion from self-feed to floor feeding (Willrich 1966).

Climatological Effects-

Temperature dependence of waste constituent generation for different production units is necessary to refine and transfer data obtained under a variety of climatological conditions. Data in previous tables were generally unspecified as to temperature or season; hence, probably represent a variety of conditions. Physiologic information (Mount 1968) indicated a 40 percent increase in water intake between 20° C and 30° C with concomitant urine increases.

Two references were available on seasonal effects, Table 24. The waste load from a concrete slab unit was determined in which there was some confounding effect due to frequent pen washing (Taiganides 1964). The total waste, total solids, and total volatile solids generation rates were found to be reduced by 50 percent, 37 percent, and 35 percent, respectively, during a summer period as compared to tests conducted in winter and spring. In a partial-slatted confinement house, water use was reduced by use of nipple waterers, a timed sequence fogging system responding to ambient pen temperature, and floor scraping with waste stored in the pit for two weeks prior to emptying (Overcash 1973). The waste volume showed a slight increase during the warmer periods. The COD, TOC, and TKN expressed as kg/d/45-kg hog or as a ratio of a given parameter to orthophosphorus (a conservative element) did not evidence large shifts between cold and warm periods. Therefore, it was concluded that seasonal generation changes were not large. At this time, satisfactory studies for evaluating the climatological influence on waste generation are limited.

Typically, a slotted floor-manure pit facility will be operated until the pit is full and then overflow to a lagoon will occur until pit emptying is feasible. The nitrogen concentration of the pit supernatant or overflow liquid was found to be about one third of the completely mixed pit contents (Overcash 1973, Sewell 1975). If this overflow or a sample of pit liquid without careful depth integration were used to determine pit losses of waste parameters, a higher apparent loss would result. Some literature data citing high nitrogen losses in pit storage may result from inadequate sampling.

A complete summary of the waste generation rate judged as most reliably representative of concrete slab and slotted floor production units was made, Table 25. This is a compilation of Tables 15-23. From this table, the hypothetical concentration of raw swine waste without excess water can be directly calculated. Values in Table 25 were used as the input to pretreatment processes in determining process performance.

SWINE WASTE LOAD FROM DRYLOT AND PASTURE PRODUCTION UNITS

Swine drylot or pasture units represent both a functional system for finishing hogs and the most often employed facility of the three production categories. In contrast, the waste load generated, the environmental impact, and the relative economics are the least documented. Also, in comparison to the considerable research on beef feedlots and more recently dairy loafing areas, the swine drylot has received negligible attention. Miner (1970)

Table 24. SEASONAL EFFECT ON RAW SWINE WASTE PARAMETERS

Reference	Dates	Average air temperature, °C	Raw swine waste, kg/d/45-kg hog				
			TS	VS	COD	TKN	t-P0 ₄ -P
Taiganides 1964	Jan	12	0.39	0.29	--	--	--
	Aug	27	0.22	0.18	--	--	--
	Apr	18	0.44	0.36	--	--	--
Overcash 1973	June-Aug	24	--	--	0.21	0.014	0.004
	Sept-Nov	14	--	--	0.27	0.016	0.005
	Dec-Feb	7	--	--	0.27	0.018	0.005
	Mar-May	16	--	--	0.38	0.028	0.009
	June-Aug	24	--	--	0.25	0.013	0.004

Table 25. SUMMARY OF SWINE WASTE GENERATION FROM CONCRETE SLAB AND SLOTTED FLOOR-PIT PRODUCTION UNITS

Parameter	Generation rate, g/d/45 kg hog	Parameter	Generation rate, g/d/45 kg hog (unless noted otherwise)
Total waste mass (density = 1.0 g/cm ³)	3800 (3.8t/d/45 kg hog)	Chemical oxygen demand	300
Total solids	230	Biochemical oxygen demand (5 day)	120
Volatile solids	180	Total organic carbon	90
Total suspended solids	180	Alkalinity (as calcium carbonate)	0.002
Volatile suspended solids	160	Volatile acids (as acetic acid)	15
Nitrogen	18	Crude fiber	45
Ammonia - Nitrogen	9	Ether extract	20
Phosphorus	6	Crude protein	65
Potassium	8	Nitrogen - free extract	90
Calcium	9	Fat	4.5
Magnesium	2	Inorganic carbon	18
Sodium	2	Gross energy	900 kcal/d/45 kg hog
Iron	0.45		Generation rate, billions of counts/ d/45 kg hog
Zinc	0.14	Fecal coliform	0.04 - 13 (literature range)
Copper (no feed copper supplement)	0.02	Total coliform	0.6 - 42 (literature range)
(feed copper supplement 150-350 ppm) 0.2		Enterococcus group	0.8 - 38 (literature range)
Manganese	0.055	Streptococci	0.1 - 320 (literature range)
Boron	0.001	Escherichia coli	0.4 (order of magnitude)
Chloride	14	Aerobes	4000 (order of magnitude)
Sulfur	3	Aerobes	2000 (order of magnitude)
Cadmium	0 - 3x10 ⁻⁴	Facultative organisms	4000 (order of magnitude)
Aluminum	0.14		
Cobalt	0.002		
Molybdenum	0 - 9x10 ⁻⁵		
Lead	0.003		

concluded several years ago that "although runoff from feeding areas confining animals other than cattle may be expected to be high in organic matter, no data are currently available concerning these sources". A recent assessment of swine waste (Overcash 1975) stressed the need to evaluate waste generation and design of swine feedlot controls. United States Environmental Protection Agency and some state regulations now require retention and land application of all runoff from production areas which do not maintain vegetative cover. Therefore, there is an urgent need to obtain data for application of these regulations to swine drylots since these units are usually operated at lower stocking densities, do not accumulate manure packs, and are managed in a different manner than beef feedlots. The design and economics of such controls will be a function of differing runoff retention structure requirements, projected annual pumping costs, and nutrient value of runoff liquid.

Waste defecated in a swine drylot or pasture is subject to a number of processes resulting in constituent changes. The major waste migration pathways or effluents from a feedlot are: 1) rainfall and snow melt runoff, 2) decomposition, volatilization, and incorporation into soil and/or plants, and 3) movement with soil water to either surface waters or ground water. In perspective, the most visible and currently scrutinized effluent by regulatory agencies is drylot rainfall runoff. This effluent stream can be controlled, collected, and handled in an environmentally acceptable manner. A study (Barker 1976) was recently begun at a producer site to determine swine drylot runoff quantities and constituent transport, stream impact, and natural or background runoff and constituent transport from a comparable set of geographical conditions. Volatilization, decomposition and soil incorporation losses represent the greatest effluent pathway because most swine drylots are seldom scraped or develop the manure pack characteristic of beef feedlots.

The soil water movement or percolation losses are the least understood and at present, very little research or control technology is being directed to this loss pathway. Descriptions of soil-manure properties, interconversions between forms of nitrogen, etc., are not available. A recent study (Spray 1974) suggests that drylot rotation and subsequent crop harvesting can have an advantageous impact on reducing potential soil-water transport of waste constituents. Further estimation of waste movement by this pathway is not included in this report because of the lack of even descriptive data on lot conditions. The attendant conclusion is a strong recommendation for research and documentation of the total environmental impact of swine drylots.

The production unit waste generation for swine drylot or pasture units is thus taken to be runoff and the resulting constituent transport. This evaluation is limited by several factors, the first of which is that no direct data for lot runoff were available in the literature. However, one closely associated study (Robbins 1972) on the pollutional potential of swine area runoff was performed on a watershed basis. In the study of watersheds, swine waste was applied to a plant-soil system, hogs raised on drylots, and even some direct stream access by swine. Comparisons were made to natural pollutional load on streams draining adjacent agricultural lands devoid of farm animals. Mass balances for the watershed with 200 sows on 1.2 hectares of drylot plus wastes from 300 confined hogs spread on 2 hectares show that 0.69 percent, 1.66 percent and 3 percent of the defecated BOD₅, TOC and nitrogen, respectively, was present in the stream draining that watershed. Their conclusions included that even in cases when disposal sites are poorly located or where swine are grown on dry lot the amount of pollutants (natural plus animal wastes) that reach streams is less than 10 percent of the raw waste deposited in the watersheds.

As another data limitation, the available feedlot information for volume and parameter concentrations are for beef feedlots, predominantly located in the Midwest. Thus, waste generation for swine drylots are necessarily extrapolated from beef feedlot data. Some interchangeable basis is needed since swine stocking densities on drylots are not as high as most beef units. Possible interconversion factors are the animal weight per unit of feedlot area or differences of nitrogen defecated per unit of feedlot area. A final data limitation is the documented data variability for feedlot pollutant transport at a given site (Clark 1975).

Under these conditions, the determination of swine drylot or pasture runoff waste generation was developed as a range of probable values. That is, an envelope of probable maximum and minimum runoff transport was established. The upper limit is taken to be beef feedlot runoff while the minimum is taken to be runoff transport from established plant-soil systems receiving recommended rates of swine waste.

Rainfall runoff is usually expressed as cm of runoff and has been correlated to precipitation and to antecedent soil moisture conditions (Edwards 1975). There appears to be little effect of feedlot slope, animal ration, or animal stocking density on runoff volume (Clark 1975). The investigated densities for beef lots are listed in Table 26 along with comparable swine stocking, both expressed as liveweight per unit area and based on defecated nitrogen per unit area. The equivalent liveweight swine stocking densities to that of beef feedlots

Table 26. TRANSLATION OF STUDIED BEEF FEEDLOT STOCKING DENSITIES (CLARK 1975) INTO EQUIVALENT SWINE DRYLOT STOCKING DENSITIES.

Feedlot Location	Beef Stocking rate		Equivalent stocking rate for swine based on liveweight animals/ha.	Equivalent stocking rate for swine based on kg N defecated per animal live- weight, animals/ha.
	m ² / animals	animals /ha.		
McKinney, Tx.	9	1,100	8,900	4,500
Bushland, Tx.	12	830	6,700	3,400
Ft. Collins, Col.	19	530	4,200	2,100
Mead, Neb.	19	530	4,200	2,100
Pratt, Ks.	33	300	2,400	1,200
Bellville, Tx.	35	290	2,300	1,200
Gretna, Neb.	46	220	1,700	850
Sioux Falls, S.D.	53	190	1,500	750

range from 1,500-8,900 animals/ha. which is substantially above the usual swine densities (125-500 animals/ha.). Since the runoff volume was found to be relatively insensitive to stocking density, the runoff per unit of liveweight generally decreases in a linear manner as stocking increases.

Concentration ranges for runoff liquid from concrete surfaced cattle feedlots are: COD, 2,760 mg/l (Miner 1966) to 48,000 mg/l (Wells 1972). Total nitrogen values (ammonia plus organic) range from 94-1,000 mg/l (Miner 1966) to 68-1,057 mg/l (Wells 1972). Nitrate values are from 0.1-11 mg/l (Miner 1966) to 0-1,270 mg/l (Wells 1972). Suspended solids are about 1,100-13,300 mg/l (Miner 1966).

Concentration ranges for runoff from unpaved cattle feedlots are: COD from about 1,300-8,247 mg/l (Gilbertson 1970) to 10,900-286,000 mg/l (Gilbertson 1971). Total nitrogen (ammonia plus organic) range from 50-540 mg/l (Miner 1966) to 1,500-10,000 mg/l (Gilbertson 1971). Nitrate values are from 0-17 mg/l (Gilbertson 1971). Suspended solids are about 1,100-7,000 mg/l (Miner 1966) to 2,400-17,400 mg/l (reported as percent total solids, Gilbertson 1970).

Winter runoff values for an unpaved cattle feedlot were reported (Gilbertson 1970) to be: 14,129-77,804 mg/l COD, 1,429-5,765 mg/l total nitrogen, and 30,000-198,000 mg/l total solids.

Subsequent articles (Gilbertson 1971 and McCalla 1972) continue to reference previously reported findings (Gilbertson 1970) that only 3 to 6 percent of the material deposited on beef feedlots will be transported in rainfall runoff. Conclusions presented (Gilbertson 1970) were that about 6 percent of the volatile solids deposited on unpaved beef feedlot surfaces was transported in runoff for lots with stocking rates of 19 m²/head and 3 percent for stocking rates of 9.5 m²/head. If winter runoff was included, the corresponding percentage values were 14 percent and 26.8 percent. Differences among COD values were not apparent for the different types of feedlots studied or the cattle densities of 19 and 9.5 m²/animal (Gilbertson 1970). Doubling cattle population densities from 490 to 980 per hectare was reported to increase pollutional potential of runoff by only 25 percent (Lippper 1969). The runoff pollutant concentrations were approximately twice as great for a concrete lot as for an unsurfaced lot (Lippper 1969 and Miner 1966). In a summary of these and other data, the runoff concentrations were variable, but a discernable trend of proportionally increasing concentration with increasing stocking was evidenced, Table 27. Runoff liquid concentrations of around 400 mg TN/l at about 40 m²/head increased to around 1,500 mg TN/l at 10-20 m²/head, a roughly linear relationship.

Table 27. AVERAGE OR TYPICAL RAINFALL RUNOFF LIQUID CONCENTRATION OF TOTAL NITROGEN - BEEF FEEDLOTS OF VARIOUS STOCKING DENSITIES (Clark 1975)

Location	Stocking Density m ² /animal	Average or typical total nitrogen con- tent of runoff liquid, mg TN/l
McKinney, Tx	9	1,140
Bushland, Tx	12	1,530
Mead, Neb.	19	150
Ft. Collins, Col.	19	1,750
Pratt, Ks.	33	750
Bellville, Tx	35	90
Sioux Falls, S.D.	53	300

Total beef feedlot runoff transport per unit liveweight is about the same regardless of stocking density or unit type because of the general relationship between runoff volume and concentration. Although this analysis is approximate, it does corroborate conclusions of various researchers that about 5 percent of defecated waste load leaves feedlots as runoff (Madden 1971 and Gilbertson 1970). The range of runoff transport is about 3 percent to 10 percent of the defecated waste and increases directly with annual rainfall. Thus, runoff transport can be normalized by the amount of runoff (a direct proportion to the amount of rainfall is assumed) to give the mass of a constituent per head per cm of runoff (Environmental Protection Agency 1973).

Using a maximum of 10 percent of defecated waste for feedlot rainfall transport and the raw waste amounts in Table 25, an upper value for swine drylot was calculated, Table 28. These production unit waste loads are the input to subsequent pretreatment processes such as retention ponds or are the amounts of material available for direct land application. The amount of a given constituent per cm of runoff was calculated based on certain assumptions in a later section describing runoff retention ponds.

The lower limit of estimated swine drylot or pasture runoff is the transport found from areas receiving applications of animal waste at recommended rates of 300-600 kg N/ha./yr. Based on the raw waste defecated, these land application rates would be equivalent to 40 to 80 hogs per hectare. Such a stocking density is just on the border between a pasture situation and a drylot in terms of ability to support a vegetative cover (Dobson 1975). Therefore, results presented here for runoff transport from areas receiving recommended rates of animal waste will represent: 1) the approximate waste load from pasture production units averaging 40-80 hogs/ha., and 2) a lower estimate of runoff transport from swine drylots.

Several data sources were found for runoff concentrations, Table 29. The concentrations are 20 to 1,000-fold lower than feedlot values indicating primarily the much lower amount of waste constituents per unit area. On a mass balance basis (Humenik 1976) the percent of applied swine lagoon effluent material which appeared in rainfall runoff from Coastal Plains-Bermuda grass plots was between 0.9 percent and 4.3 percent for TN, COD and t-PO₄-P. Thus, approximately 2.5 percent of the applied waste load was assumed to appear in runoff transport from plots receiving the equivalent of fertilizer recommendations and thus this value was used to determine the lower limit on drylot production unit waste load, Table 28. While it is anticipated that the percent

Table 28. ESTIMATED MAXIMUM, MINIMUM AND AVERAGE RAINFALL-RUNOFF TRANSPORT OF SWINE WASTE FROM DRYLOT PRODUCTION UNIT

Parameter	Minimum generation rate (2.5% of defecated load), g/d/45-kg hog	Maximum generation rate (10% of defecated load), g/d/45-kg hog	Average drylot generation rate (5% of defecated load), g/d/45-kg hog
Total waste mass	90	360	180
Total solids	5.5	23	11
Volatile solids	4.5	18	9
Total suspended solids	4.5	18	9
Volatile suspended solids	4	16	8
Nitrogen	0.45	1.8	0.9
Ammonia - Nitrogen	0.2	0.9	0.4
Phosphorus	0.15	0.55	0.3
Potassium	0.2	0.8	0.4
Calcium	0.2	0.8	0.4
Magnesium	0.055	0.22	0.11
Sodium	0.055	0.22	0.11
Iron	0.01	0.04	0.02
Zinc	0.003	0.014	0.007
Copper (no feed copper supplement)	5.5×10^{-4}	0.0022	0.0011
(feed copper supplement, 150-350 ppm)	0.0045	0.018	0.009
Manganese	0.0015	0.006	0.003
Boron	3×10^{-5}	12×10^{-5}	6×10^{-5}
Chloride	0.4	1.6	0.8
Sulfur	0.38	0.32	0.36
Cadmium	$8-8.7 \times 10^{-5}$	2.8×10^{-5}	$8-1.4 \times 10^{-5}$
Aluminum	0.003	0.014	0.007
Cobalt	4.5×10^{-5}	1.8×10^{-5}	9×10^{-5}
Molybdenum	$8-2 \times 10^{-6}$	$8-8 \times 10^{-6}$	$8-6 \times 10^{-6}$
Lead	8×10^{-5}	3.2×10^{-5}	1.6×10^{-5}
Chemical oxygen demand	8	32	16
Biochemical oxygen demand (5 day)	3	12	6
Total organic carbon	2	8	4
Alkalinity (as calcium carbonate)	4.5×10^{-5}	1.8×10^{-5}	9×10^{-5}
Volatile acids (as acetic acid)	0.4	1.6	0.8
Crude fiber	1	4	2
Ether extract	0.5	2	1
Crude protein	1.5	6	3
Nitrogen - free extract	2	8	4
Fat	0.1	0.4	0.2
Inorganic carbon	0.4	1.6	0.8
Gross energy	22 kcal/d/45-kg hog	98 kcal/d/45-kg hog	45 kcal/d/45-kg hog
Generation rate, billions of counts/d/45-kg hog			
Fecal coliform	0.001-0.3	0.004-1.3	0.002-0.6
Total coliform	0.015-1	0.06-4.2	0.03-2
Enterococcus group	0.02-1	0.08-3.8	0.04-2
Streptococci	0.0025-8	0.01-32	0.005-16
Escherichia coli	0.01	0.04	0.02
Anaerobes	100	400	200
Aerobes	50	200	100
Facultative organisms	100	400	200

Table 29. CONCENTRATIONS OF RAINFALL RUNOFF FROM LAND RECEIVING ANIMAL MANURE AND FROM PASTURE OR CONTROL AREAS.

Source	Concentration of rainfall runoff liquid, mg/l				
	TN	BOD5	o-P04-P	t-P04-P	Ca
Sewell 1972					
heavily grazed pasture and resting area	4.5	14	7.1	-	-
heavily grazed pasture and resting area	5.1	17	1.2	-	-
McCaskey 1973					
irrigated dairy manure (3,900 kg N/ha./yr)	15-35	20-107	-	4-14	
tank spread dairy manure (1,700 kg N/ha./yr)	15-25	30-45	-	4-5	
no manure application	7-12	11-14		2-4	
Overcash 1974					
swine lagoon effluent application					
300 kg/ha./yr	2-20			0.5-3.5	1-12
600	2-20			0.5-3.5	1-20
1,200	5-35			1-8	
control	1-10			-	
Loehr 1974					
land receiving manure	1-12	-	-	0.3-4	-
crop land	9-10	-	-	0.02-2	-

of waste in animal runoff would also be directly proportional to annual rainfall or runoff volumes, no comparative data were found and so a single percent (2.5 percent) was used.

Pasture production waste load is estimated to have as an upper limit the 2.5 percent of the defecated waste as translated from experiments described in Table 29. A lower limit on pasture production runoff transport are concentration results from the background controls or checks used in previously cited studies, Table 29. The control data for pasture area under recommended management were one-fourth to one-third of the amount of pollutant transport from waste applied areas. Thus, a lower limit on pasture production waste load is 0.6 percent to 0.8 percent of defecated waste load. Applying this percentage to raw swine waste yields minimum constituent generation rates for pasture runoff, Table 30. The two columns in Table 30 represent the upper and lower limits descriptive of pasture swine production. An average of these is 1.5 percent of the defecated waste load which is taken as pasture production unit effluent.

The one available study involving swine drylots (Robbins 1972) as well as land application, concluded that 0.69 percent, 1.66 percent and 3 percent of the defecated BOD₅, TOC, and TN reached the stream. These results are impacted by attenuation zones between drylots and the stream; and therefore, these percentages are necessarily low although the nitrogen value was within the range of estimated swine drylot runoff transport.

It is important to note that results for beef feedlots and extrapolated percentages for swine drylot and pasture production are generally for the period 1966-1972. Subsequently, significant research progress and design modifications (Shuyler 1973) have resulted in considerable reduction of runoff transport. Therefore, with sound application of these techniques and adaptations for swine drylot and pasture conditions there will result in significant reduction in the waste production values in Tables 28 and 30. Data on production unit runoff should be a high priority to allow most economical compliance with regulatory constraints.

In summary, the swine drylot waste load as rainfall runoff was taken to be between 2.5 percent and 10 percent of the defecated waste load while the pasture production units yielded between 0.7 percent and 2.5 percent of the defecated waste load. As approximate average values, 5 percent and 1.5 percent were selected as representative of the rainfall-runoff waste load from swine drylot and pasture production facilities, respectively. Such single percentages represent crude estimates since no differentiation is made among decomposition modes, mobile conservative constituents, soil bound compounds, or specific feedlot conditions.

Table 30. ESTIMATED MAXIMUM, MINIMUM AND AVERAGE RAINFALL-RUNOFF TRANSPORT OF SWINE WASTE FROM PASTURE PRODUCTION UNIT

Parameter	Minimum generation rate (0.75 of defecated load), g/d/45-kg hog	Maximum generation rate (2.55 of defecated load), g/d/45-kg hog	Average pasture generation rate (1.55 of defecated load), g/d/45-kg hog
Total waste mass	25	90	55
Total solids	1.5	5.5	3.3
Volatile solids	1.3	4.5	2.7
Total suspended solids	1.3	4.5	2.7
Volatile suspended solids	1.1	4	2.4
Nitrogen	0.13	0.45	0.3
Ammonia - Nitrogen	0.06	0.2	0.1
Phosphorus	0.04	0.15	0.09
Potassium	0.06	0.2	0.1
Calcium	0.06	0.2	0.1
Magnesium	0.015	0.055	0.03
Sodium	0.015	0.055	0.03
Iron	0.003	0.01	0.006
Zinc	0.1×10^{-4}	0.003	0.002
Copper (no feed copper supplement)	1.5×10^{-4}	5.5×10^{-4}	3.3×10^{-4}
(feed copper supplement 150-250 ppm)	0.0013	0.0045	0.002
Manganese	4×10^{-4}	0.0015	9×10^{-4}
Boron	0.8×10^{-5}	3×10^{-5}	1.8×10^{-5}
Chloride	0.11	0.4	0.24
Sulfur	0.02	0.08	0.05
Cadmium	$0-0.2 \times 10^{-5}$	$0-0.7 \times 10^{-5}$	$0-0.4 \times 10^{-5}$
Aluminum	8×10^{-4}	0.003	0.002
Cobalt	1.3×10^{-5}	4.5×10^{-5}	3×10^{-5}
Molybdenum	$0-0.6 \times 10^{-6}$	$0-2 \times 10^{-6}$	$0-1 \times 10^{-6}$
Lead	2×10^{-5}	6×10^{-5}	5×10^{-5}
Chemical oxygen demand	2	8	5
Biochemical oxygen demand (5 day)	0.8	3	2
Total organic carbon	0.6	2	1
Alkalinity (as calcium carbonate)	1.3×10^{-5}	4.5×10^{-5}	3×10^{-5}
Volatile acids (as acetic acid)	0.1	0.4	0.24
Crude fiber	0.3	1	0.6
Ether extract	0.15	0.5	0.3
Crude protein	0.4	1.5	0.9
Nitrogen - free extract	0.6	2	1.2
Fat	0.03	0.1	0.06
Inorganic carbon	0.1	0.4	0.3
Gross energy	6 kcal/ g/45-kg hog	22 kcal/ g/45-kg hog	13 kcal/ g/45-kg hog
Generation rate, billions of counts/d/45-kg hog			
Fecal coliform	0.003-0.08	0.001-0.3	0.0006-0.2
Total coliform	0.004-0.3	0.015-1	0.009-0.6
Enterococcus group	0.006-0.3	0.02-1	0.01-0.6
Streptococci	0.007-2	0.0025-8	0.0015-5
Escherichia coli	0.003	0.01	0.006
Anaerobes	30	100	60
Aerobes	15	50	30
Facultative organisms	30	100	60

SECTION VI

PRETREATMENT PROCESSES

OVERVIEW

A large number of processes which receive the waste load from the various swine production housing units have evolved. These are referred to as pretreatment processes since: 1) these facilities are operated prior to some terminal receiver system, Figure 3, 2) the use of these units results in further reduction of the generated waste load for some or all of the waste constituents, and 3) such unit processes alone or in combinations are a part of the total swine production-waste management system. Pretreatment processes are to be differentiated from waste handling unless the waste handling results in reduction of waste constituent(s) load. The swine waste pretreatment facilities are in one of five categories or groups, depending on the design philosophy or objectives of the total system, Figure 11.

The first category is that of zero pretreatment in which swine wastes generated in the housing units are conveyed by one of many alternative means (scrape, flush, etc.) in a direct manner to the plant-soil receiver system. Such minimal pretreatment involves a large area of technology and development research, but does not significantly alter the total waste load. While this category is important, since it represents direct land application and a means to achieve a high level of plant nutrient recovery, it will not be elaborated in this discussion of pretreatment processes affecting the swine waste load.

A number of pretreatment alternatives are in a second category where the basic design philosophy is to alter the amount of the land limiting constituents (LLC) in swine waste so that the area of plant-soil receiver is reduced. In large part, these processes result in loss of nitrogen and other nutrients and might thus be termed as predominantly destructive. In this category are lagoons (anaerobic, mechanically aerated, or facultative), runoff retention facilities, oxidation ditch,

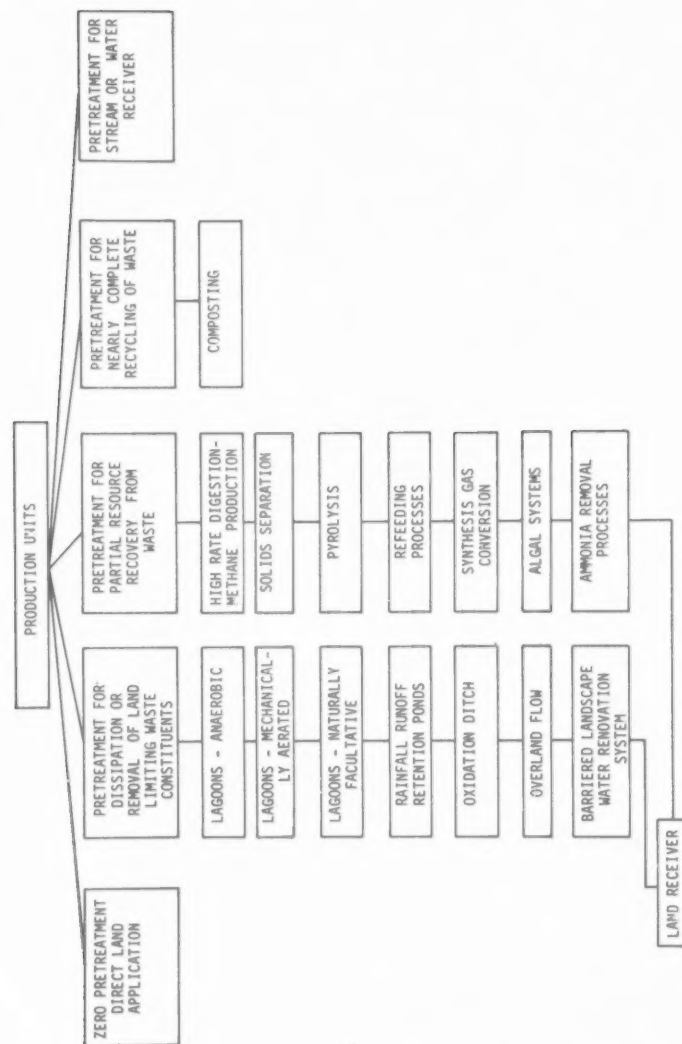


Figure 11. Pretreatment alternatives for swine wastes.

barriered landscape water renovation system, and overland flow systems. In the following detailed analysis of pretreatment processes, sufficient data were not found to evaluate the barriered landscape water renovation system. All of these unit processes have effluents which have been reduced in the land limiting constituent (nitrogen), but which still contain a significant waste load to a land receiver system. The design of the total waste management system is an economic balance between the costs of LLC(s) pretreatment removal and land application pursuant to minimal total system cost.

In the third pretreatment group are those processes which employ either a separation or a conversion stage in order to utilize some waste fraction. These utilization schemes result in waste recycling, but also have an effluent or unutilized portion which must be land applied. The pretreatment alternatives are in essence nondestructive. They are not designed necessarily to reduce the LLC(s) but to recover valuable constituents. In this third category are methane production, solids separation, pyrolysis, hydrogasification, synthesis gas production, algal or hydroponic systems, combustion, ammonia recovery units, refeeding, drying-refeeding, fermentation and direct refeeding or other waste conversion processes followed by refeeding. The following detailed process analysis does not include hydrogasification, synthesis gas, algal or hydroponic systems, combustion or ammonia recovery because of insufficient data on animal waste performance or extrapolatable mechanisms.

The fourth category of pretreatment alternatives involves processes which primarily recycle or utilize the waste. The resultant effluents are quite small and represent minor disposal problems. This group is also basically nondestructive, resulting in a much higher or complete level of swine waste recycle and recovery. Processes in this group are composting, pyrolysis, hydrogasification.

The final category of pretreatment processes involve units which are predominantly aerobic in operation and are designed along conventional municipal and industrial approaches for stream discharge. Treatment demands for stream discharge of swine waste are exceedingly severe and expensive. In this category, researchers have investigated activated sludge (Laak 1974), extended aeration (Hermanson 1967), sludge dewatering (Hepherd 1975), and nitrification-denitrification (Prakasam 1974a). Because of the variety of other alternatives more suited to satisfying present and future federal and state regulations, this pretreatment category is not detailed in this report. The reader is directed to the references cited above for design information in this pretreatment category.

PRETREATMENT PROCESSES ORIENTED TOWARD ALTERING THE LLC OF SWINE WASTE

Lagoons - Anaerobic

Waste Constituent Reduction Mechanisms-

The anaerobic lagoon is a useful pretreatment process for both reduction of the swine waste load from production units and as a management tool to better integrate constant waste generation with the specific intervals for optimal land application. There are different pathways or mechanisms for lagoon removal of the various waste constituents. Likewise from the management standpoint, there are a variety of possible lagoon design and operating variables which must be specified to satisfy the total waste management system objectives.

The overall removal pathways for an anaerobic lagoon are illustrated in Figure 12. In simplified stages, the raw waste enters the lagoon, a fraction settles, a variety of chemical and biochemical transformations occur both in the sludge and the supernatant including sludge-supernatant transfer of breakdown products, and finally, excess liquid is removed for land application. Lagoon seepage is acknowledged to occur in many systems, but the loss magnitude after initial soil sealing and the environmental impact of such losses have only been recently evaluated. In a Virginia study of a one-year old swine lagoon located in a poorly drained, high water table soil, there was pollutant movement at a 3-m distance but none at 15 m (Collins 1975). Limited, but similar findings were reported for two other producer swine lagoons in Virginia (Collins 1975). Test wells located at 3, 7.7, 14, 21.5, 29 and 300 meters from a swine lagoon have been used to demonstrate the degree of constituent movement (Smith 1975). Concentrations were elevated at the 3 and 7.7 m wells over that in the remaining wells. This is a new lagoon and tests after soil sealing should indicate reduced environmental impact. A similar, more detailed testing program of three established swine producer lagoons in South Carolina has been started and should yield more results concerning seepage and impact (Hegg 1975).

Monitoring before and after waste input for a dairy lagoon system indicated that after 2 months, the initially elevated concentration levels at 30 m from the lagoon had returned to previous levels (Sewell 1975). Under high groundwater conditions in Florida (Nordsted 1971), in which clay layers reduced vertical movement, several years of monitoring at horizontal distances from an anaerobic and facultative dairy lagoon have shown little pollutant seepage at 30 meters. A California monitoring program detected effective soil sealing for a dairy lagoon after 4 months from startup and several mechanisms for the

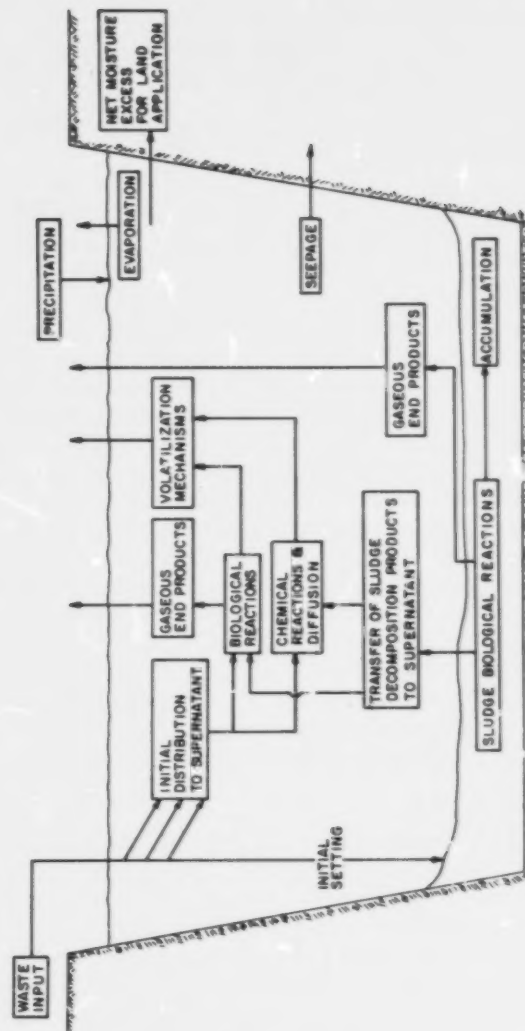


Figure 12. Pathways for removal or stabilization of swine waste in an anaerobic lagoon.

PRETREATMENT PROCESSES ORIENTED TOWARD ALTERING THE LLC OF SWINE WASTE

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reduction in seepage losses were proposed (Davis 1973). In summary, these preliminary studies indicate lagoon sealing may be expected within about 6 months after which the area of seepage impact becomes restricted to approximately 10 meters.

Nitrogen loss from anaerobic lagoons occurs primarily as surface volatilization of ammonia (Koelliker 1973, Miller 1976). Because of the high fraction of ammonia in raw waste and lagoon supernatant Table 25, the conversion of organic nitrogen to ammonia does not appear to be a limiting step in nitrogen loss (Humenik 1976). Secondary nitrogen losses can be attributed to the net solid material remaining in the lagoon sludge. Initial nitrogen loss due to settling has been determined to be approximately 40 percent of the input swine waste; but after sludge biological activity and transfer to the supernatant, the net amount of nitrogen loss to the sludge is about 25 percent (Howell 1976). A tertiary nitrogen loss mechanism is the volatilization of short chain organic compounds such as amines. While this pathway probably is small as a nitrogen loss, the impact as an odor or nuisance problem is well documented (Miner 1968, Barth 1971, and White 1971).

The salts in swine waste, expressed on an elemental basis, are removed in an anaerobic lagoon by chelation-settling or precipitation. Losses of various cations can range from less than 10 percent to over 90 percent. The Irving-Williams series for soil organic chelates or the degree of element electronegativity was shown to be useful in predicting cation removal in swine lagoons (Overcash 1976), thus verifying losses by settling and chelation. Direct analysis of phosphate solubility limits and precipitate crystals (Booram 1973) and concentration response in lagoons (Humenik 1976) indicate phosphate precipitation occurs in lagoons.

Organic constituents of swine waste are removed in anaerobic lagoon systems primarily by microbial stabilization and subsequent release of methane and carbon dioxide. Net sludge settling also accounts for about 30 percent losses of both total organic carbon (TOC) and chemical oxygen demand (COD). As with organic nitrogen compounds, some surface losses due to volatilization of short chain molecular occurs.

Many microorganism transformations occur in anaerobic lagoons. The lagoon supernatant microbial populations at the usual range of lagoon loading rates (0.03 to 0.50 kg COD/week/m³) are very much underutilized (Humenik 1976), especially in relation to high rate anaerobic digestors designed for maximum methane generation. Research investigations of *Salmonella* species, total coliform, and fecal coliform survival in anaerobic swine lagoons indicated that within 20-30 days dieoff was

essentially complete (Krieger 1975). Porcine enterovirus was found to be undetected analytically or by pig infection after 4 days of anaerobic residence time (Meyer 1971). Under conditions of epidemic use of antibiotics plus sulfa drugs in swine feed, a carry-over effect was found with subsequent rapid lowering of the lagoon microbial populations (Clark 1965). On discontinuation of antibiotics, the lagoon copper medicinal supplements (150-300 ppm in feed) even over a continuous 10-year period did not produce adverse effects on microbial performance in an anaerobic lagoon (Overcash 1976b). Thus, anaerobic swine lagoons with typical residence times of greater than 300 days would be expected to give substantial pathogen dieoff and maintain strong, mixed populations of microorganisms for organic decomposition.

Odor resulting from anaerobic degradation of swine manure can become a nuisance. The causative volatilization process can be controlled to a certain degree by lagoon loading rate. An approximate estimation of lagoon odor (Humenik, 1976) determined that: 1) between 0.22 and 0.45 kg COD/week/m³ lagoon there is a threshold of odor, and 2) regardless of loading rate, lagoons will have an odor although the percentage of days when the odor is offensive decreases drastically as the loading intensity decreases. A Texas investigation determined that the swine production housing facility had a substantial odor intensity (Reddell 1975a), thus continuing the question of the relative odor from a lagoon versus a production house.

Design and Climatological Factors-

Estimation of anaerobic lagoon performance in terms of liquid concentrations is dependent on a number of factors. For anaerobic lagoon pretreatment performance assessment, the effect of contributory liveweight, lagoon volume and configuration, temperature, periods of freezing weather, annual rainfall, and frequency of loading are considered in detail in this section. The primary determinant of effluent quality is contributing liveweight or loading intensity. Detailed monitoring (Humenik 1976) of lagoon supernatant quality and cyclic production unit liveweight has demonstrated a rapid concentration response. The total Kjeldahl nitrogen (TKN) was particularly responsive to liveweight with lag times of approximately 4 weeks. COD and TOC were found to respond less rapidly. Phosphate concentrations were insensitive to cyclic contributory liveweight. These data indicate the need to document production unit liveweight at least as frequently as concentration since even temporary increases or decreases can affect lagoon performance. At larger production facilities where fluctuations in liveweight are small in comparison to total liveweight routine concentrations monitoring is sufficient.

In comparison of two or more swine production units with similar contributory liveweight, the most important lagoon design factor is the volume provided per unit of liveweight (m^3 lagoon/45-kg hog). A more universal and technically based expression of lagoon design rate is to divide the daily production unit waste load of COD (or VS) by the lagoon volume to yield a loading rate such as kg COD/d/m^3 lagoon volume. This loading criterion was studied under controlled field conditions (Humenik 1976) and the results demonstrated a nearly linear increasing relation between effluent or supernatant concentration (COD, TOC, TKN) and lagoon loading rate, Figure 13-15. This increasing relationship is in agreement with the removal mechanisms for both organic and nitrogenous compounds. Phosphate was less dependent on loading until the highest input rate at which hindered settling and solubility became controlling. Over the span of investigated lagoon loading rates ranging from 0.03-3.6 kg COD/week/m^3 lagoon [less than the criteria for naturally aerobic lagoons (Soil Conservation Service 1970) to greater of any current recommendation] the TKN concentration varied by a factor of 330 indicating the importance of documenting accurately the lagoon loading rate when comparing literature values. Surface area is also a factor in odor and nitrogen losses, hence, lagoon monitoring programs should specify the complete lagoon dimensions as well as the loading rate. The relative importance of surface area, lagoon volume, and other physical factors has not been fully delineated.

Another operational factor which has not been fully examined is lagoon loading frequency. In a series of laboratory lagoons, the frequency of loading was varied from once per hour to once per three weeks in units receiving the same total waste load (Howell 1974). Several total waste loads were also tested. No significant effect of frequency was evidenced for COD, TOC, or TKN concentrations at swine waste loadings of 1.15 and 4.6 kg COD/week/m^3 lagoon. However, at a lower loading of 0.28 kg COD/week/m^3 lagoon, a 30 percent lower COD and TOC supernatant concentration resulted with continuous loading. These studies indicate that at higher loading rates the advantage of continuous input is masked while at lower rates, possibly lag times associated with cyclic batch, growth patterns reduce biostabilization rates below steady-state conditions. The effect of frequency on nitrogen concentrations appears to be negligible; but is not fully defined at this time. In any case, the frequency of loading effect was judged to be smaller, secondary determinant of effluent quality.

The frequency of lagoon loading may, however, be a large factor in performance when very infrequent, large loads are introduced to a lagoon. Such shock loading can result in overloaded conditions and

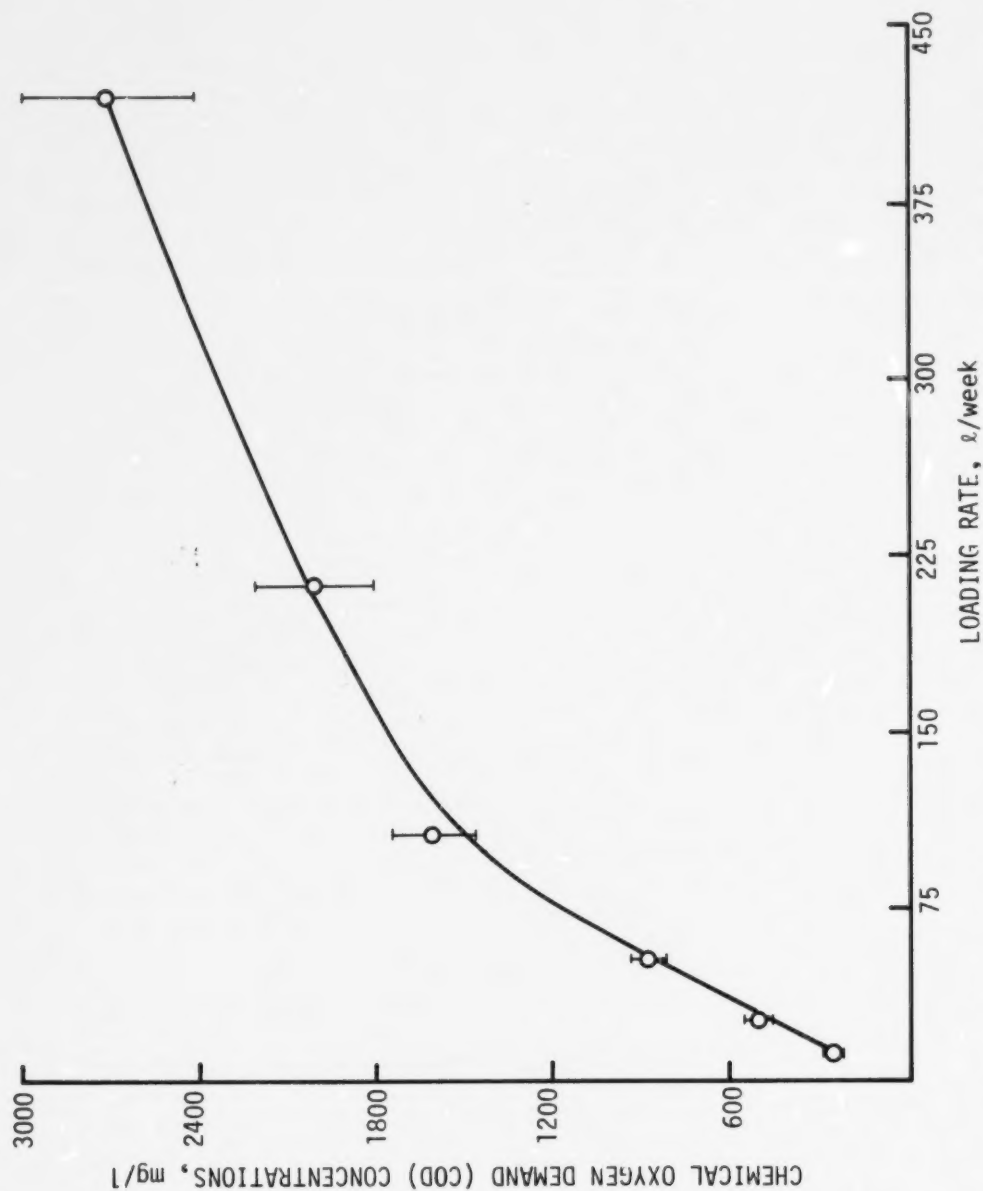


Figure 13. Steady-state supernatant COD concentrations for pilot-scale swine lagoons receiving various loading rates (Humenik, 1976).

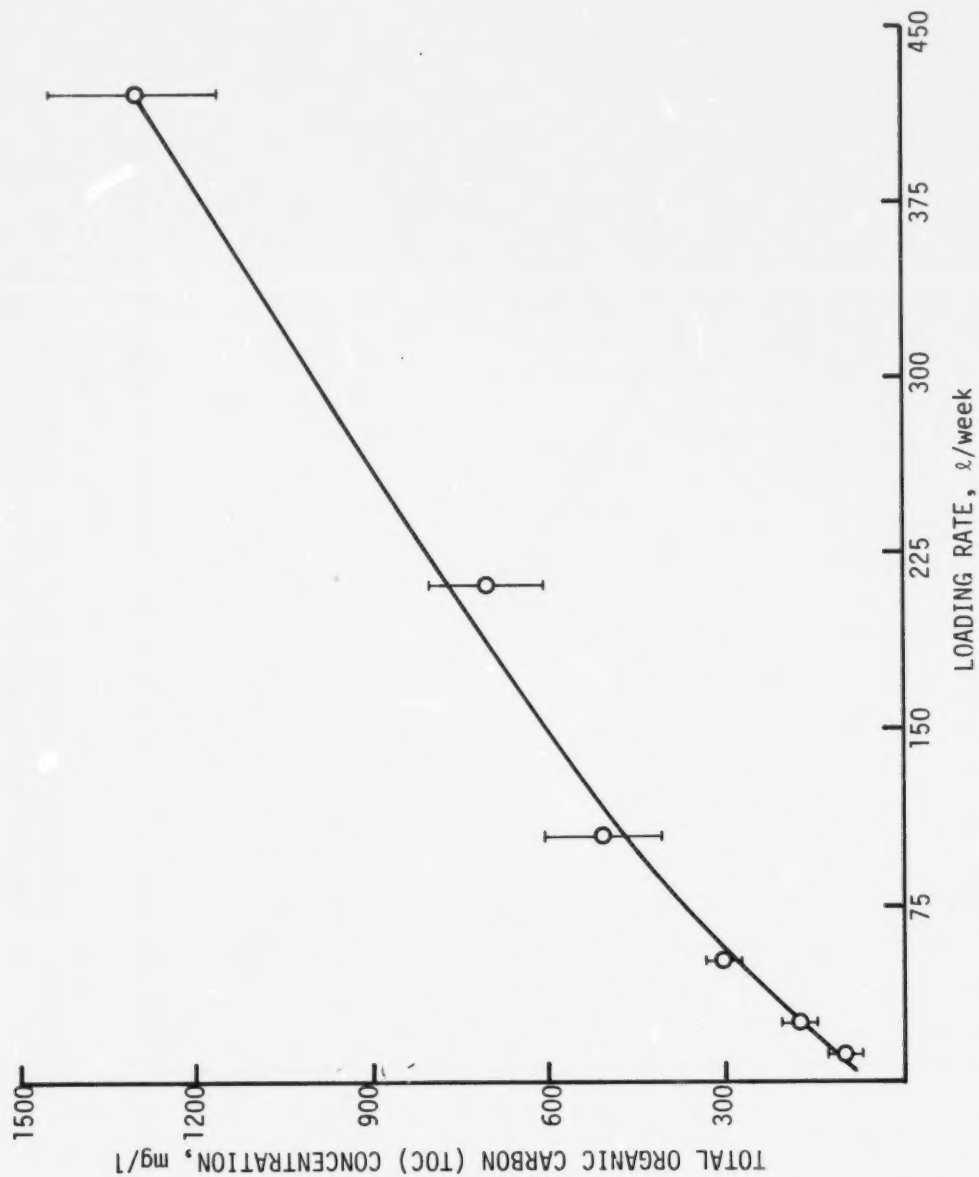


Figure 14. Steady-state supernatant TOC concentration for pilot-scale swine lagoons receiving various loading rates (Humenik, 1976).

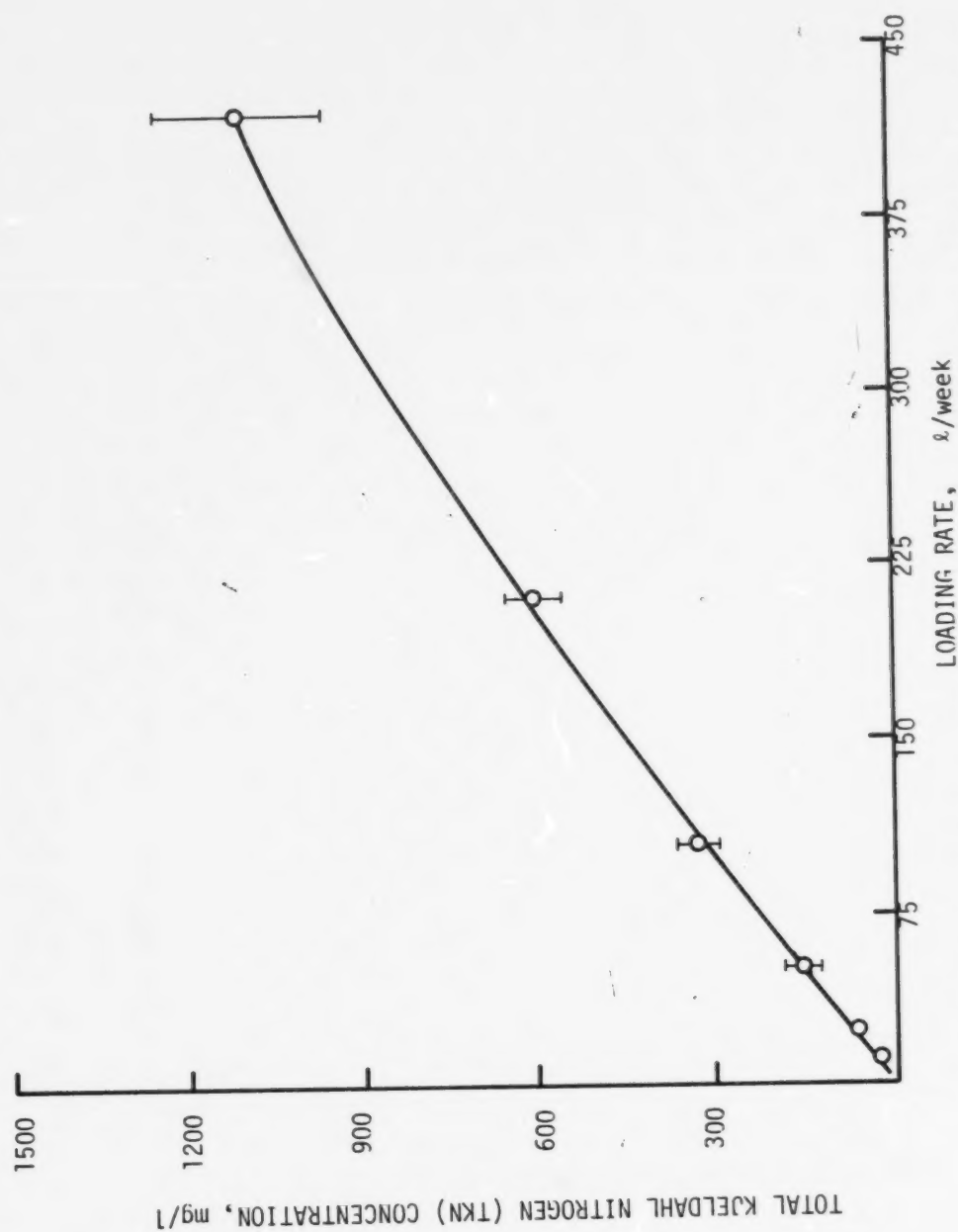


Figure 15. Steady-state supernatant TKN concentration for pilot-scale swine lagoons receiving various loading rates (Humenik, 1976).

inhibition of biological activity. Studies have been undertaken to determine the probability of lagoon failure due to shock loadings (Willrich 1966) and it was concluded that for loading rates less than $0.27 \text{ kg VS/week/m}^3$ lagoon there was little probability of shock failures. Since anaerobic lagoon response to shock loads is very complex and failure is not certain, but is expressed on a probability basis, the practice of infrequent pulse inputs is not invalid, but should be regarded as a very marginal practice. For similar technical reasons, the loading of a nearly empty lagoon with raw waste (after irrigation or drawdown) should not be recommended. Similarly, other adulterants added to lagoons such as large doses of diesel oil for mosquito control can lead to potential performance problems. Thus, for frequency of lagoon loading between once per month and continuously, the effluent concentration in a producer lagoon is relatively independent of frequency.

In order to compare lagoons with similar size and contributory loading rates between various climatic regions, information on temperature, rainfall, and freezing conditions are needed. The temperature or seasonal effects on lagoon concentration were determined under Iowa conditions (Koelliker 1973). The range of TKN concentration for a lagoon loaded at $0.33 \text{ kg VS/week/m}^3$ was 200 to 600 mg TKN/l or ± 50 percent of the annual average, 400 mg TKN/l. This 50 percent variation is an estimate of the seasonal variation in lagoon concentration and demonstrates the need to document the date or lagoon liquid temperature when monitoring. It would appear, however, that in comparison to the effect of lagoon loading rate the seasonal temperature influence is not as great a factor.

The effect of frozen surfaces on lagoon effluent TKN concentrations represents another seasonal factor. A mass balance on nitrogen can be performed to judge this effect by assuming no $\text{NH}_3\text{-N}$ volatilization losses and no settling pattern changes when the surface is frozen. Sludge composition would be determined by the fraction settled since little biological sludge breakdown and retransfer to the supernatant is expected at these temperatures. Initial TKN settling has been determined to be 40 percent (Howell, 1976). The resulting increase in supernatant concentration above the concentration at freezing for several lagoon loading rates over a 0-6 month period are shown in Figure 16.

The change in nitrogen concentration calculated after 3 months of frozen conditions represents an increase of 30-60 percent above the lagoon concentration prior to surface freezing. A 60-120 percent increase would occur after six months depending on the loading rate. Comparison of these changes to the average cycle of TKN concentrations

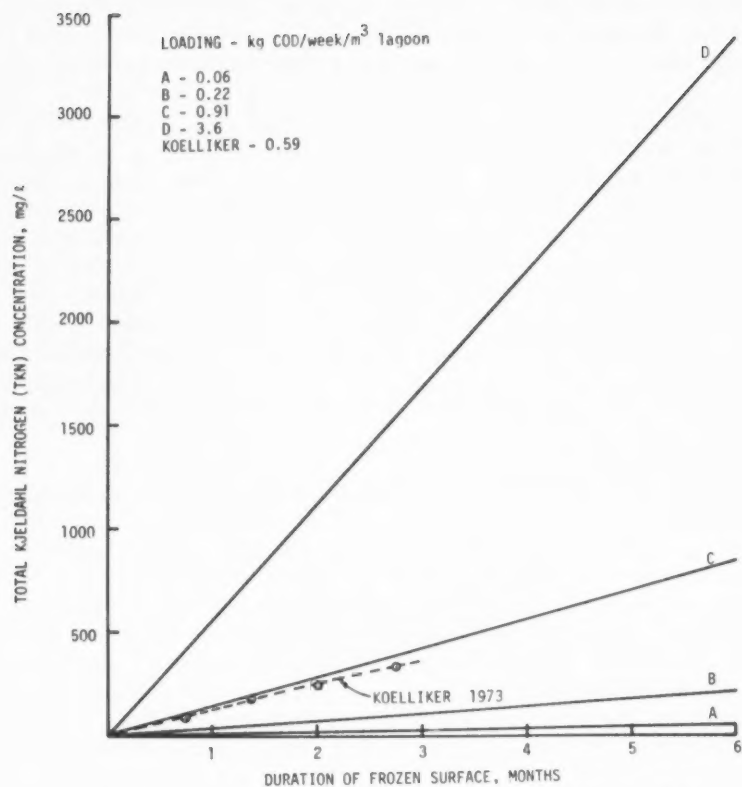


Figure 16. Increase in lagoon concentration anticipated for periods of freezing conditions.

in studied North Carolina lagoons in which winter temperatures are around 0°C but no consistent freezing occurs (Howell 1976), indicates that the freezing effects are greater than seasonal temperature changes on ammonia volatilization. Corroboration of frozen surface effects on swine lagoon supernatant TKN concentration were obtained in Iowa (Koelliker 1973) showing a nearly linear increasing relation with time, Figure 16. The lagoon loading rate was about $0.33\text{ kg VS/week/m}^3$ of lagoon.

Rainfall input varies considerably on a national basis and represents an additional liquid volume which must be handled. The volume of liquid which must be removed from a lagoon to maintain steady operation is the net moisture excess (wastewater plus rainfall minus the pan evaporation). Data obtained for a dairy waste pond in which the moisture loss from a pond with bottom sealing and a floating pan test in the same lagoon were within 0.43 cm/month of each other (Pratt 1975) show pan evaporation can represent lagoon evaporation.

On a broad geographic basis, approximate levels of net rainfall input can be calculated from maps depicting moisture balance areas, the expected swine waste input, and lagoon specifications. With the assumption of 7.5 l/d/45-kg hog as the swine waste volume, the ratio of the net moisture excess (*i.e.* total volume of waste plus rain minus evaporation) to the production unit waste volume was determined for various climatic moisture deficits in the United States, Figure 17. The national map of moisture deficits is presented in Figure 18 to relate these data to specific geographic areas.

In moisture excess regions, there is a cost advantage in terms of reduced rainfall volume to be handled for lagoons with a smaller surface area. On a design basis, this may mean a deeper unit or a higher loading rate (*i.e.* less lagoon volume per hog). The net rainfall input for North Carolina lagoons (about 38 cm of moisture excess) sized to control odors $9.2\text{ m}^3/45\text{-kg hog}$ represents about 75 percent more lagoon liquid handling when the production waste load is 7.5 l/d/45-kg hog . Production waste loads at the minimum of 3.8 l/d/45-kg hog would be increased about 150 percent due to the net moisture input. Many large hog production states in the Great Lakes area are in the moisture excess region of about 25 cm for which the net rainfall excess liquid is about 50 percent, still a substantial increase. The extra liquid to be handled can be made less than 20 percent of the waste load for all the moisture excess regions by using a heavier lagoon loading rate.

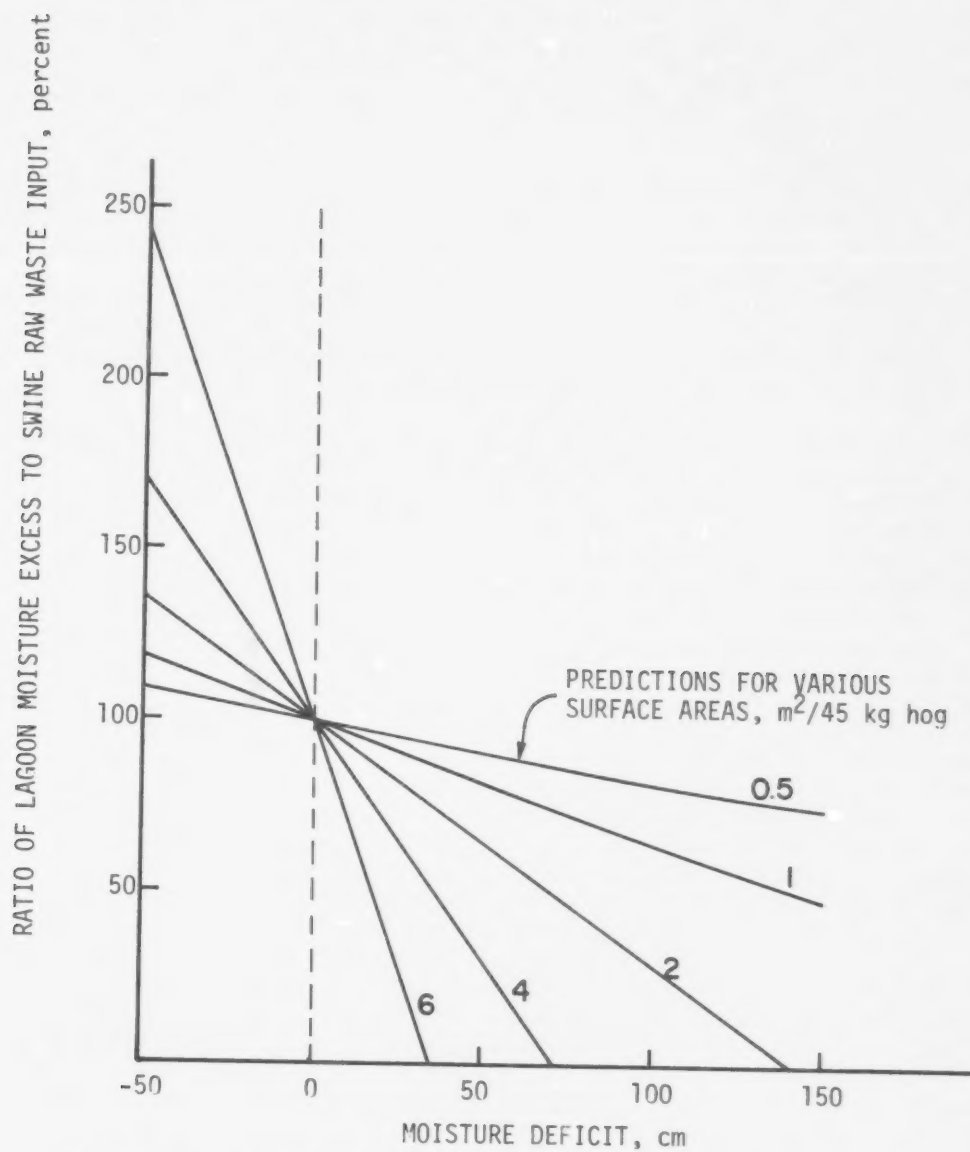


Figure 17. Impact of regional level of moisture deficit for various lagoon designs of m^2 of surface area/45-kg hog assuming a constant depth of 2 m.

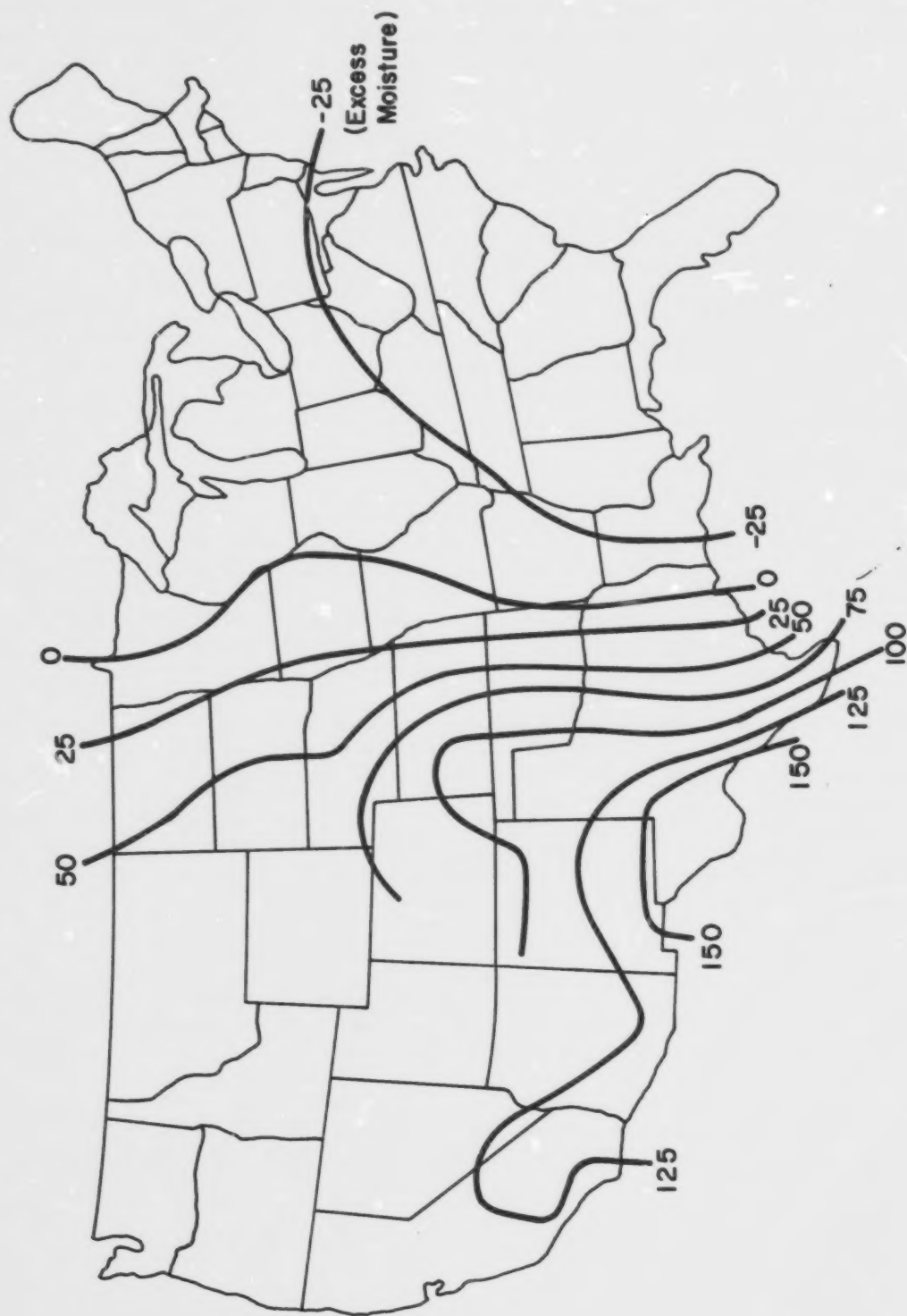


Figure 18. Lines of moisture deficit (in centimeters) for the United States (Chow, 1964)

In moisture-deficit regions, the lagoon represents a liquid reduction technique, Figure 17. Again, these volume reductions, while not affecting the total land area needed for lagoon effluent, do reduce the transportation costs (pumping and hauling). The major hog production states of Iowa, Missouri, and Minnesota are in the 12 to 25 cm moisture deficit range and thus have a reduction of the production unit waste volume to 30-60 percent of the estimated 7.5 l/d/45-kg hog. The net liquid loss from these systems provides a cost advantage to large surface area, shallow lagoons or lagoons at lower loading rates. This contrasts with the cost trends for moisture-excess regions and should be considered in proposed lagoons recommendations. For a swine waste load of 7.5 l/d/45-kg hog and a given moisture-deficit region the swine lagoon loading rate ($m^2/45\text{-kg hog}$) at which evaporative losses match rainfall and waste inputs can be deduced from Figure 17. The intercept of surface area lines (interpolated if necessary) with the zero net lagoon moisture excess ratio axis yields this swine loading rate in surface area/45-kg hog.

Anaerobic Lagoon Effluent-

The supernatant or effluent concentration of a number of chemical constituents has been determined by either periodic or aperiodic field sampling of farm scale producer or university units or by controlled comparative studies of lagoon variables. Field monitoring is the basis for the majority of available swine lagoon data, but is severely limited by the uncontrolled and unmeasurable variables. In particular, the average annual swine input is usually estimated but is not sufficiently accurate to assess the contributory liveweight as demonstrated by the high sensitivity of lagoon concentration to changes in unit liveweight. In addition, little, if any, climatological or seasonal variables are reported to define temperature variations. These obvious limitations insure that data variability will be high. In addition, nonuniform sampling techniques which include algae or scum layers would produce variability. As a positive aspect, lagoon supernatant has been found to be very nearly uniform with respect to position; hence, depth or relation to influent pipe are probably not significant in sampling (Overcash 1976b).

There are not many controlled studies of long duration on a well documented facility or to compare several loading rates, but this approach is evolving and will yield data in which contributory liveweight is fixed or at least documented, seasonal effects are recorded, and a uniform sampling and analysis scheme is used.

In the present review of swine lagoons, data from all sources were utilized since these represent approximations of actual field conditions and the present state-of-the-art is insufficient to put the data on

a more normalized basis. Nitrogen content of lagoon effluent or supernatant from 12 sources was plotted versus the loading rate expressed as kg VS/d/m³ lagoon (calculated from the raw waste generated and the lagoon volume per unit weight of contributing animals), Figure 19. The percent reduction in nitrogen is difficult to assess since the influent concentration or effluent volume are unspecified in many of the literature studies but effluent concentration appears to be related to loading rate. Thus, relying on the few more extensively monitored studies, a lagoon mass balance was approximated. At the commonly recommended lagoon loading rate of 0.54 kg VS/week/m³ lagoon, the effluent quality was 700-1,200 mg TKN/l which on an annual cycle was 30-50 percent of the influent (assuming 7.5 l of wastewater/d/45-kg hog). Thus, the nitrogen loss was about 60 percent at this loading. By similar calculations, the percentage reduction at 1.08 and 0.13 kg VS/week/m³ lagoon were 30 percent and 85 percent, respectively. Applying these percentages to the raw waste input yields the amount of nitrogen leaving lagoons with these loading rates and thus, the lagoon pretreatment performance.

Removal of cations and anions was documented for 7 lagoons, Table 31. While only three of the studies documented the influent (Collins 1975a and Overcash 1973, 1976b) and effluent on a mass basis, these three studies were used to evolve the percentage removal of selected cations, Table 31, because of variable water use and the effect on concentrations in other studies. The effluent concentrations, Table 31, provide an estimate of the liquid loading intensities. These data are limited; and therefore, the percent removals to sludge zone are very approximate. The effluent calcium, potassium, sodium, and chlorine concentrations are about 75 percent of the influent while magnesium, copper, manganese, and zinc are present at about 10 percent of the influent levels. The amount of these parameters in the effluent, g/d/45-kg hog, were determined, Table 32, from these percentages and the raw waste loads.

Literature data on the relationship between organic parameters (COD and BOD₅) and loading rate were more variable, Figure 20. These analyses were utilized in many of the early studies in which there was little specification of critical operational variables. The percent removal was determined as with TKN for a waste input of 40,000 mg COD/l and 16,000 mg BOD₅/l.

Effluent COD and BOD₅ as a percent of influent for 1.08, 0.54 and 0.13 kg VS/week/m³ were: 40 percent - 60 percent and 25 percent - 40 percent; 10 percent - 25 percent and 10 percent - 20 percent; and 2 percent - 10 percent and 3 percent - 6 percent, respectively. These calculated values which were within literature ranges, were used to determine lagoon effluent levels in Table 32. These percentages and the raw waste generation were used to determine the lagoon effluent amounts for three loading rates, Table 32.

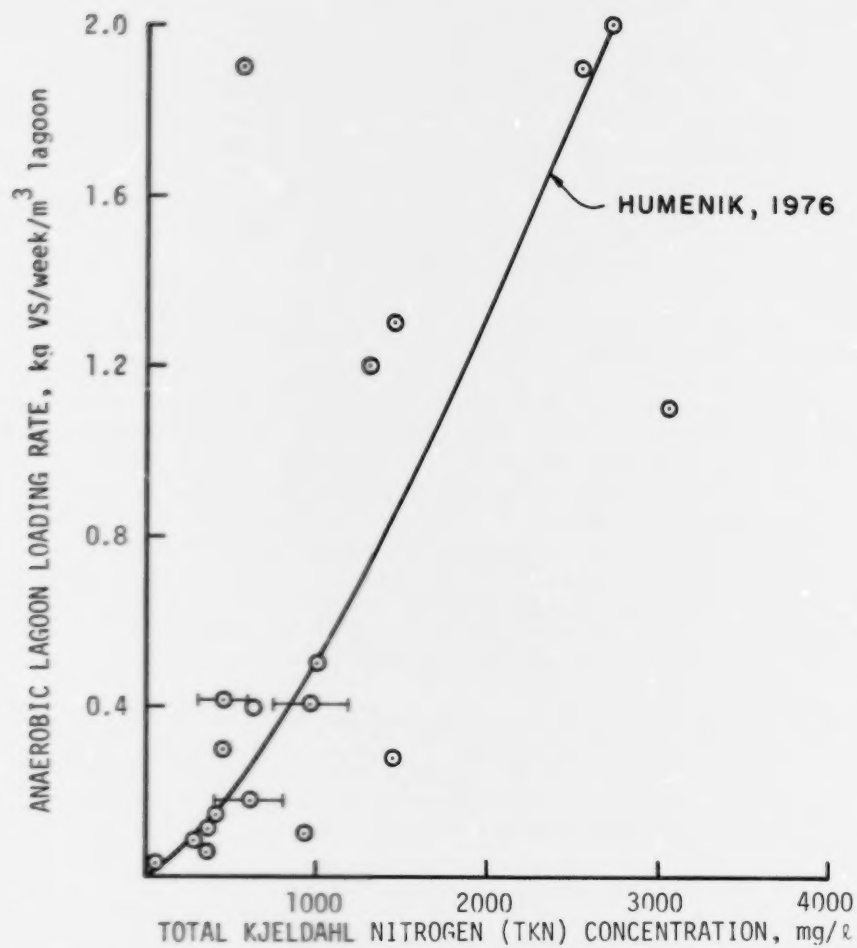


Figure 19. Effluent concentration of TKN reported for swine lagoons loaded at various rates.

Table 31. EFFLUENT CONCENTRATION OF VARIOUS CATIONS AND ANIONS FROM ANAEROBIC SWINE LAGOON, EXPRESSED AS ELEMENTS

Reference	Loading rate, kg COD/week/m ² lagoon	K	Na	Ca	Mg	Cu	Zn	Mn	Cl	Al	Ml	B	Cr	Fe	Pb	Mb	Conduc-tivity
Mutlak 1975	--	700	115	58	2	0.8	2	0.8	2								
Overcash 1976b	0.5	240	103	54	58	0.5	0.45	0.4									
Collins 1975a	0.2	340		72	45	0.1	1.4	0.3	335								5,400
Sievers 1975	0.7	496	220	106		0.2	1.3										
Overcash 1973	0.9	825	480	124	29	0.3	1.7	1.0									
Willrich 1966	0.6-0.8	105															
Widest plan Service 1975	--	302		51	53	0.55	0.45	0.7		5.6	0.4	0.65	3.1	2.8	1.5	0.02	5,000
Effluent concentration as a percentage of Influent, Collins 1975a and Overcash 1976b		75%	75%	20%	60%	3%	10%	15%	75%								

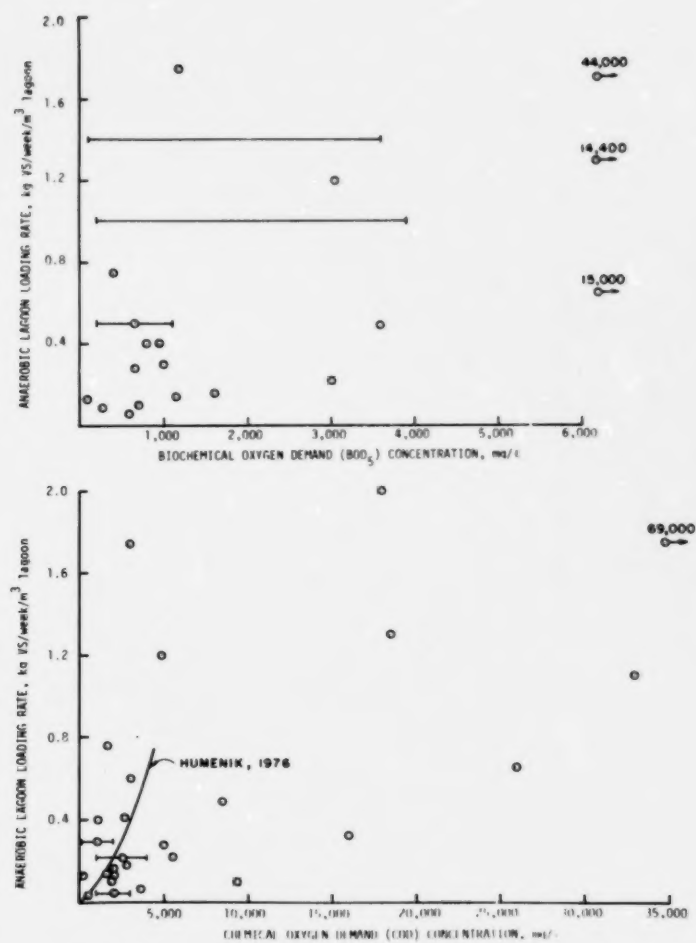


Figure 20. Effluent concentrations of COD and BOD₅ reported for lagoons loaded at various rates.

Table 32. APPROXIMATE PRETREATMENT PERFORMANCE OF ANAEROBIC SWINE LAGOON BASED ON PRODUCTION
RAW WASTE INPUT, TABLE 25

Parameters	Lagoon loading rate, kg VS/week/m ² lagoon	
	1.1	0.55
Effluent, g/d/45-kg hog		
Nitrogen	13	5 - 9
Phosphorus	0.6	0.4
Potassium	6	6
Sodium	1.5	1.5
Calcium	1.5	1.5
Magnesium	0.2	0.2
Copper	0.002 - 0.02	0.002 - 0.02
Zinc	0.01	0.01
Manganese	0.005	0.005
Chloride	10	10
Chemical oxygen demand	115 - 185	35 - 75
Biochemical oxygen demand, BOD ₅	30 - 45	15 - 25
Effluent rate, billions of counts/g/45-kg hog		
Coliform	--	0.001 - 0.8
Fecal coliform	--	0.0004 - 1
Fecal streptococci	--	5 x 10 ⁻⁶ - 50
Enterococcus	--	8 x 10 ⁻⁶ - 0.02

Lagoon monitoring for various microbial species has resulted in a range of values, Table 33. The percentages remaining in the effluent are order of magnitude assessments from which the expected reduction due to lagoon pretreatment was calculated, Table 32. A dependence of microbial population on the COD of the effluent was postulated in an Alabama study (Koon 1970) which would imply that different loading rates would yield varying levels of biological indicators but to date detailed confirmative studies have not been performed.

In summary, the anaerobic lagoon is a flexible pretreatment process which can be designed or operated to yield a variety of effluent concentrations. With respect to nitrogen, a lagoon can be used for nitrogen conservation or for dissipating the majority of the input nitrogen. The producer's total system objectives and costs should be considered in specifying lagoon design and operation. In moisture-deficit regions, the salt content and cation balance should also be considered in land receiver determinations since these constituents are only slightly changed by lagoon pretreatment. Heavy metals, as may occur in swine waste, are substantially removed by lagoon pretreatment.

Lagoon - Mechanically Aerated

Mechanical aeration is used primarily for oxygen input, odor control and nitrogen removal (Hermanson 1972, Dale 1969, Miller 1976). The floating surface aerator is most common, Figure 21, but fixed aerators or subsurface diffused air systems could be employed. Surface aeration allows the design of a smaller lagoon per unit of liveweight because of enhanced stabilization or volatilization removal of waste constituents created in the aerobic surface zone and continued settling and anaerobic degradation in the lower zone. Odor constituents generated in the anaerobic zone are mitigated in the top aerobic zone.

Waste constituent removal mechanisms for anaerobic lagoons are altered by the introduction of a floating aerator. Nitrogen loss is enhanced by the improved supernatant - air contacting associated with the spray plume discharge of such aerators (Overcash 1976). The larger surface area created and the opportunity for reducing the air transfer resistance lead to increased ammonia volatilization losses. The nitrification-denitrification pathway for nitrogen loss with surface aeration cannot be verified nor dismissed at this time since only limited total nitrogen data are available. The fact that nitrate does not accumulate does not mean that this pathway is not operating, but at this time the relative magnitude nitrogen loss mechanisms cannot be determined.

Table 33. EFFLUENT CONCENTRATIONS OF BACTERIA FROM ANAEROBIC SWINE LAGOON

Reference	Effluent concentration, millions of species/100 ml				
	Fecal Coliform	Coliform	Enterococcus	Fecal Streptococci	Salmonella
Clark 1965		1.4	0.012		rare
Koon 1970	0.08-1.9				
Arial 1971	0.4				
Robbins 1971	0.2-1.0	0.4-2		0.5	
Collins 1975a	0.3				
Barth 1975		0.3-0.5			
Total range	0.08-3	0.3-2	0.012	0.5	
Effluent concentration as a percentage of influent using Table 25	1%-10%	0.2%-2%	0.001%-0.05%	0.005%-15%	

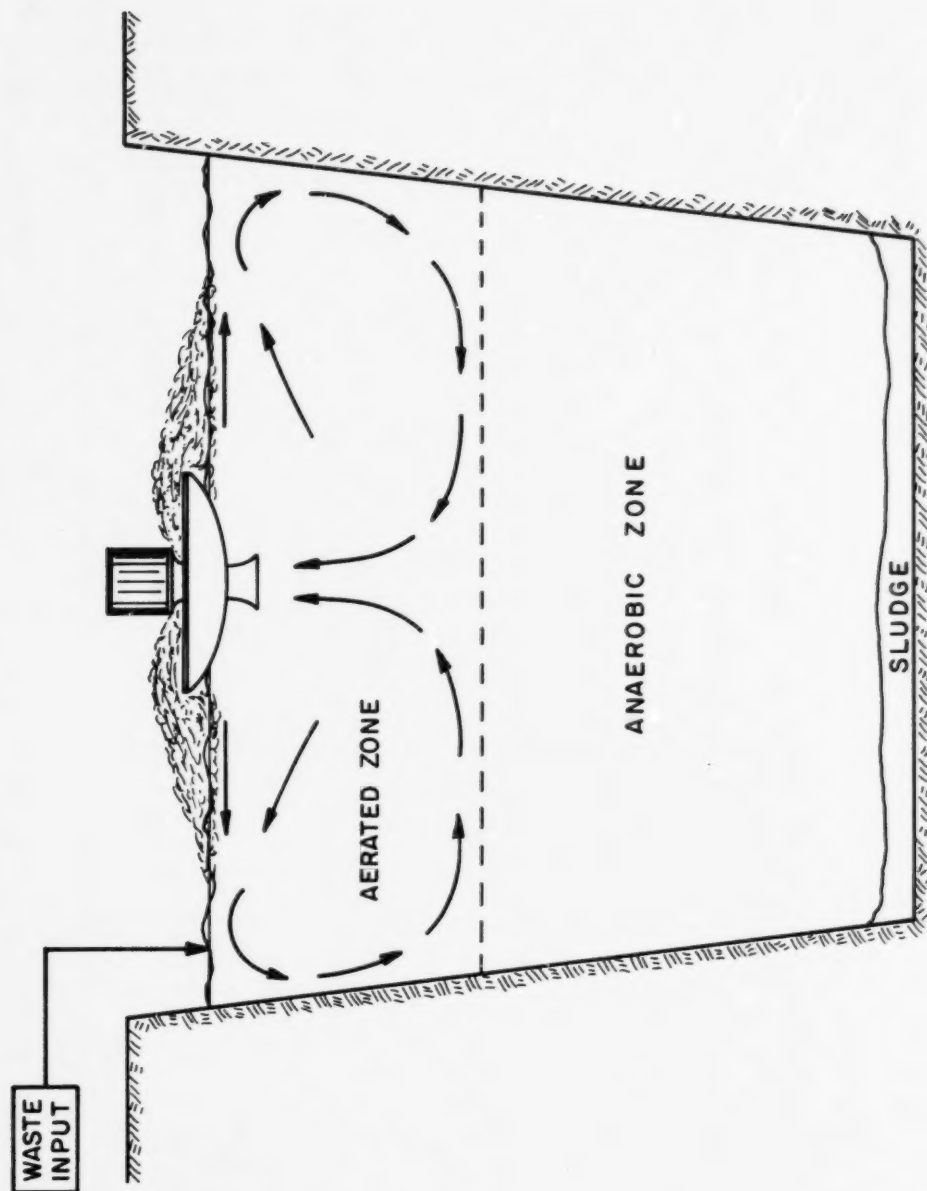


Figure 21. Schematic of mechanically aerated swine lagoon.

Input of oxygen from mechanical aeration enhances the stabilization of organic matter (Miller 1976), although no residual dissolved oxygen levels are routinely detected. A confounding factor in assessing the impact of surface aeration has been the problem of sludge scour which increase the supernatant concentrations. That is, the influence of flow patterns generated by surface aerators (including those using anti-erosion plates to minimize bottom scour) appears to reach about 1.5 m below the surface which is the approximate depth of most lagoons. Initial data indicate that units of 3.5 m or deeper should be used to allow for swine waste settling to the sludge zone and allow full surface aeration pretreatment potential. Ultimately, the sludge will accumulate until it reaches the zone of surface aerator influence at which time sludge removal or lagoon retirement should be instituted.

With respect to cation removal, the presence of a surface aerator will probably have little influence. Surface aerators do not appear to hinder substantially the immediate settling of swine wastes (Humenik 1976); therefore, if resuspension is eliminated by use of a deep lagoon or anti-erosion shields the cation supernatant concentrations should be only slightly elevated over similarly loaded anaerobic lagoons. The slight elevation would be due to the extent of aerator-induced hindered settling. The ratio of salts to nitrogen in the effluent will increase because of ammonia losses thus requiring a re-examination of land application rates especially in moisture-deficit regions.

Design criteria and operating data for the mechanical aeration of lagoons are limited. Aeration input for odor control is specified by the oxygen demand of the waste and the lagoon configuration. Recommended aeration levels, range from 30 percent-50 percent (Dale 1969) of the input BOD_5 to 150 percent-200 percent for oxidation ditch systems. Quite possibly, the lower rates of surface aeration (Dale 1969 and Humenik 1975) are characteristic of outdoor units with natural odor dilution while the higher aeration rates (Kroeker 1975) are needed for completely confined operations. Tests in swine lagoons loaded at 1.8 kg COD/week/ m^3 volume have shown that an aerator rated at about 2.1 kg O_2 /kw/hr had about 80 percent transfer efficiency or 1.7 kg O_2 /kw/hr (Miller 1976).

It is difficult to separate oxygen or power input from the effect of lagoon configuration on effluent quality since an aerator can influence only a limited area or volume in the lagoon. Lagoon surfaces which are beyond the affected zone are subject to foam buildup and localized odor problems. A reasoned analysis and experiments of the surface area requirements are not presently available and would need to be performed on a number of aerator types. The surface area per unit of power input is given in Table 34 for several tested systems along with

Table 34. SURFACE AERATION CHARACTERISTICS FOR LAGOONS FOR ODOR CONTROL

Location	Waste	Surface dimension, m	Power, kw	Surface area per unit of power input, m ² /kw	Odor performance
Clayton, N.C.	Swine	23 x 28	3.7	175	Slight
Siler City, N.C.	Hatchery	15 x 42	11.0	57	Excess aeration
Lexington, N.C.	Swine	28 x 43	4.5	270	Unsatisfactory
Period 1		28 x 43	7.5	160	Satisfactory
Period 2		6.7 (dia.)	2.2	16	Satisfactory
Blacksburg, Va.	Swine				
Lafayette, Ind.	Dairy				
Period 1		15 x 22	1.5	220	----
Period 2		15 x 22	3.7	89	Satisfactory

general odor control judgements. Initial trial and error evaluations have indicated that about 125 m²/kw is a satisfactory operational design, but equipment variations preclude complete specification of design or operational factors.

Effluent quality estimates from surface aerated field units in which ~~sufficient depth is allowed to prevent sludge scour~~ are not presently available. All existing reported systems are not sufficiently deep as evidenced by the elevated phosphate levels over similarly loaded unaerated anaerobic lagoons (Humenik 1976). However, for units in Table 34 with depths of 1.8-2.2 m, the effluent TKN is reduced to about 30 percent of the influent. Thus, effluent nitrogen levels for surface aerated swine lagoons are about 6 g N/d/45-kg hog. Based on anticipated percent reductions and the daily raw waste amounts, Table 35, available data for oxygen demand and total organic carbon data were determined for a 1.9 m diameter unit with sludge scour and thus, are approximate values.

In terms of information gaps regarding surface aeration, the performance of field units in which the sludge zone is unaffected has not been determined for the critical constituents in land application. The economics of reduced lagoon size, aerator operations, and reduced receiver land areas need to be evaluated especially when a number of such deep units have been tested. The operational mechanisms for units with bottom scour have been established for removal of nitrogen and other parameters.

Lagoon - Naturally Facultative

Design specifications proposed for naturally aerobic swine lagoons are based on surface area per unit animal liveweight which is also a surface area per unit of daily oxygen demand input (Soil Conservation Service 1970). Removal or stabilization for naturally facultative units derive from the larger surface area in relation to anaerobic lagoons. Large surface area lagoons are generally employed to control odor rather than to achieve a high quality effluent. With respect to nitrogen these very lightly loaded lagoons with large surface areas (assuming lagoon depth is constant) have an improved mechanism for nitrogen loss via ammonia volatilization. Naturally facultative units which do not sustain supernatant dissolved oxygen represent the upper range of nitrogen loss for lagoon pretreatment.

The effect of lower lagoon loading rates for facultative performance on cation or metals removal has not been experimentally determined. However, based on previously discussed lagoon removal mechanisms, cation removal would be expected to remain approximately the same

Table 35. APPROXIMATE PRETREATMENT PERFORMANCE FOR SURFACE AERATED
SWINE LAGOON (1.8 kg COD/WEEK/m³ LAGOON), BASED ON
PRODUCTION UNIT RAW WASTE, TABLE 25

Parameter	Effluent, g/d/45-kg hog
Nitrogen	6
Phosphorus	0.6
Potassium	6
Sodium	1.5
Calcium	1.5
Magnesium	0.2
Copper	0.002-0.02
Zinc	0.01
Manganese	0.005
Chloride	10
Chemical oxygen demand	100
Total organic carbon	35

as at higher lagoon loadings. Stabilization of carbonaceous parameters (COD, BOD₅ or TOC) is improved in the facultative or aerobic systems until conditions are reached where inorganics are converted to biomass by pulse algal or bacterial growths. With respect to pathogen reduction, little field data are available, but the increased residence times in these naturally facultative lagoons should greatly enhance dieoff. Lagoon moisture balance considerations are amplified for facultative lagoons since the large surface area acts as water trap or evaporative body depending on the geographical location.

Experimental lagoons have been operated above and below the recommended loading rate for naturally aerobic lagoons (Howell 1976), Table 36, resulting in very long residence times. The range of recommended anaerobic lagoon loading among 10 Southeastern states is from 25 to 144 g VS/d/m³ volume (Barth 1975). In the units receiving 2.4 and 4.8 g VS/d/m³ reactor and in the third stage unit of a three lagoon series (first lagoon loaded at 77 g VS/d/m³ reactor) dissolved oxygen levels were periodically observed (1-15 mg/l). These dissolved oxygen concentrations were at the surface but by the one meter depth were undetectable. At higher loadings no surface oxygen levels were found. The COD concentration of the supernatant bulk was found not directly to indicate the presence or absence of dissolved oxygen (Humenik 1976). Therefore, it was concluded that a 0.6 m to 1.0 m deep unit loaded at 2.4 g VS/d/m³ volume was not completely aerobic and that still lower loading rates (possibly 2 or 3-fold lower) would be needed to achieve this with swine lagoons.

Nitrogen in the effluent was 1.4 percent and 0.6 percent of the influent for loadings of 4.8 and 2.4 g VS/d/m³ respectively, which with about 13 percent accumulation in the sludge meant that the net losses were about 86 percent for both units. The net COD and TOC losses were about 80 percent of the influent when discounted for sludge accumulation. The daily effluent constituent amount per unit was calculated for a naturally facultative pretreatment unit from these percentage removals and assuming the same cation removal determined for more heavily loaded swine lagoons, Table 37. Even at these low loading rates, the effluent quality does not approach requirements for stream discharge. The common stream effluent quality needed is BOD_u (=BOD₅+4.TKN) in the range of 20-100 mg/l as compared to values over 200 mg/l for the studied facultative lagoons.

Rainfall Runoff Retention Ponds

The performance and design of runoff structures for swine drylots must be developed from basic principles and related data because few such ponds exist and no evaluations have been reported. The unknowns

Table 36. EFFLUENT CONCENTRATION AND DESIGN SPECIFICATIONS FOR SWINE LAGOONS LOADED AS NATURALLY FACULTATIVE UNITS

Source	Loading rate			Residence time, d	Effluent concentration, mg/l			
	m ² /45-kg hog	kg BOD ₅ /d/ha.	kg VS/d/m ³ lagoon		COD	TOC	TKN	o-P ₄ -P
Soil Conservation Service recommendation 1970	27.5	70-130						
Midwest Plan Service 1975	18.0							
Humenik 1976	41.2	37	4.4	9,400	250	90	30	15
Humenik 1976	20.8	70	2.4	4,700	500	175	70	30

Table 37. APPROXIMATE PRETREATMENT PERFORMANCE OF SWINE LAGOONS
LOADED AS NATURALLY FACULTATIVE UNITS, BASED ON SWINE
WASTE LOAD IN TABLE 25

Parameter	Effluent, g/d/45-kg hog
Nitrogen	0.2-0.5
Phosphorus	0.2
Potassium	6
Sodium	1.5
Calcium	1.5
Magnesium	0.2
Copper	0.002-0.02
Zinc	0.01
Manganese	0.005
Chloride	10
Chemical oxygen demand	2-4
Total organic carbon	1-1.5

are runoff volume, constituent transport, and reductions resulting from pond storage prior to land application. In order to estimate the pretreatment effect of rainfall retention ponds, the following order of magnitude assumptions were made:

- 1) The rainfall runoff was 30 percent of the annual rainfall as approximated from beef feedlot data and interpretation of rainfall runoff models (Phillips 1976).
- 2) The amount of waste constituents transported from beef feedlots has been estimated at 5 percent of the defecated waste load (see analysis in Section 4). These beef studies are all in the dry Midwest region in which annual rainfall is about 60 cm. Thus for 30 percent annual runoff the waste transported is 0.08 percent of the defecated waste per cm of rainfall or 0.28 percent cm of runoff.
- 3) In view of the rainfall and temperature patterns of major swine producing regions, Figure 22, the maximum holding period is probably 8 months (winter) and the minimum about 4 months (high rainfall summer periods).
- 4) Retention pond losses of nitrogen and organics for the 8 month and 4 month periods are similar to lagoons receiving waste at rates of 0.54 kg VS/week/m³ (hydraulic detention of 290 d) and 108 kg VS/week/m³ (hydraulic detention of 145 d), respectively. The basic assumption is that ponds with similar detention times produce nearly the same ammonia loss and organic stabilization.

While there are recognizable limitations to these assumptions, the order of magnitude results should qualitatively indicate geoclimatic trends. The percentages of annual rainfall occurring in June, July, August and September and the remaining eight months for the regions in Figure 22 were determined using climatic data, Table 38. In order to compare various regions, the average annual rainfall was determined to calculate runoff volume, Table 38.

The movement of swine waste constituents during rainfall-runoff events was evaluated using 0.28 percent of the defecated waste load per cm of runoff. For this limited analysis the aperiodic runoff was calculated on a daily basis assuming no waste degradation on the drylot. A stocking density 27.5 m²/hog was selected as representative of swine dry lot conditions. These assumptions specify the amount of constituent waste load, g/d/45-kg hog, which enters the runoff retention pond and the corresponding liquid volume from which the nominal average concentration was evaluated to be about 65 mg TN/l. On an annual basis the

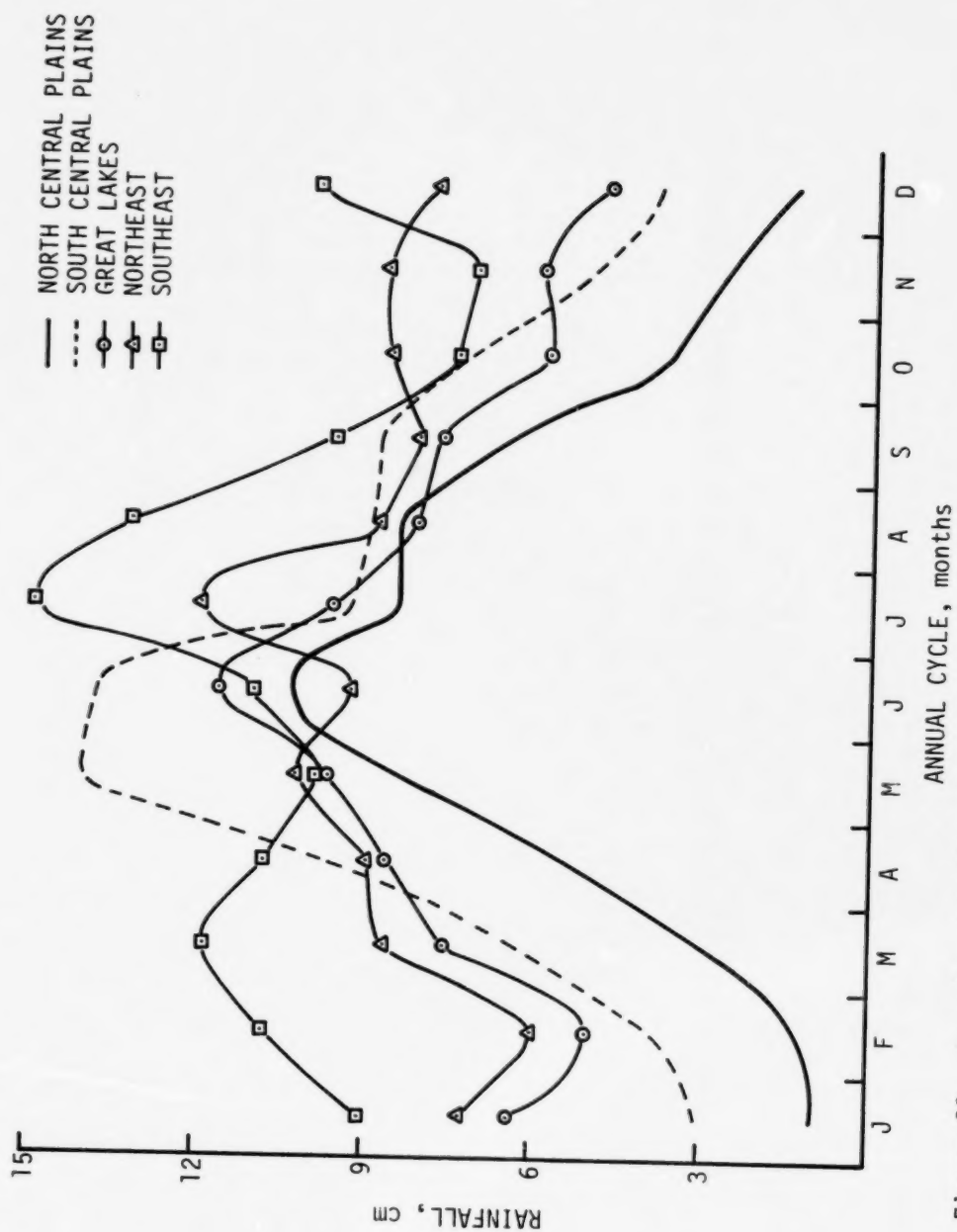


Figure 22. Annual rainfall pattern for major swine production regions of the United States.

Table 38. ANNUAL AND MONTHLY PERIOD RAINFALL, RUNOFF, AND NITROGEN TRANSPORT ESTIMATED FOR SWINE PRODUCTION REGIONS OF THE UNITED STATES, DRYLOTS

Region	Rainfall, cm		Runoff, cm		Nitrogen in runoff, g/d/45-kg hog	
	Annual	Oct-May	Annual	Oct-May	Annual	Sept-May
North Central Plains (MN, IA, WI, NE, SD, ND,	60	27	18	8	0.9	0.4
		33		10		0.5
South Central Plains (KS, MO AR, OK)	94	53	28	16	1.4	0.8
		41		12		0.6
Southeast (VA, NC, SC, AL, GA)	125	76	38	23	1.9	1.2
		49		15		0.7
Northeast (PA, NY, New England)	104	67	31	20	1.6	1.0
		37		11		0.6
Great Lakes (IL, IN, OH, MI)	91	54	27	16	1.4	0.8
		37		11		0.6

five regions representing the major swine producing areas have similar runoff constituent amounts, Table 38. The North Central Plains and the Southeast are about 35 percent below and 35 percent above, respectively, the average of all regions. Retention pond input for the 4-month, summer period was between 60 percent - 80 percent and of runoff occurring in the other 8-months period, Table 38. The greater number of large rain events during the summer was thus evidenced in the runoff amount.

The loss or percent reduction of various waste constituents which occurs during retention pond holding periods were determined according to procedures for anaerobic lagoons, Table 32. The retention pond removal was multiplied by the runoff input amounts of each waste constituent in order to evaluate order of magnitude effluent amounts, Table 39. The percent of the waste entering the runoff pond which appears as effluent nitrogen, COD, BOD₅ and TOC after the 8 and 4 month periods were 40 percent and 70 percent, 20 percent and 50 percent, 15 percent and 30 percent, and 20 percent and 50 percent, respectively. These were derived from previously described anaerobic lagoon systems of comparable residence time. The retention pond effluent for the 4 and 8 month periods was in the range of 0.5 percent - 2 percent of the defecated waste load and thus represents a sizable total removal. Nitrogen conservation can be practiced, within the limits of the amount of material in the runoff, by frequent retention pond pumping to minimize ammonia volatilization losses. The upper limit of nitrogen conservation would be the runoff nitrogen itself which would be 5 percent - 9 percent of the defecated waste load, Table 38. Total nitrogen levels in effluent from swine drylot runoff ponds are on the order of 10 - 30 mg N/l. The nominal cation concentration in retention pond liquid does not meet irrigation standards for moisture deficit regions (Reed 1972).

In summary, the system of swine drylot and runoff retention pond has not been experimentally measured but based on a series of mechanistic assumptions where effluent levels between 0.5 percent and 2 percent of the defecated waste load were derived. This pond liquid is probably salt limited in moisture-deficit regions and hydraulically limited in moisture-excess regions. For the major swine production areas, regional variations in runoff amounts were less than 35 percent of the mean for those regions.

Oxidation Ditch

Considerable research and farm scale monitoring have been accomplished for oxidation ditch pretreatment of swine wastes as well as for a number of other agricultural wastes. Consequently, there are available an

Table 39. APPROXIMATE PRETREATMENT PERFORMANCE OF RAINFALL RUNOFF
PONDS FOR SWINE DRY LOTS, BASED ON INPUT DATA TABLE 28

Parameter	Effluent, g/d/45-kg hog 8-month storage	4-month storage
Nitrogen	0.25-0.4	0.4
Phosphorus	0.015	0.02
Potassium	0.3	0.3
Sodium	0.06	0.06
Calcium	0.3	0.3
Magnesium	0.01	0.01
Copper	0.0001-0.0009	0.0001-0.0009
Zinc	0.0007	0.0007
Manganese	0.0003	0.0003
Chloride	0.6	0.6
Chemical oxygen demand	1.5-3	4-6
Biochemical oxygen demand (BOD ₅)	0.5-1	1-2
Total organic carbon	0.5-1	1-2

inclusive series of articles and reports summarizing performance, design, and operational variables (Kroeker 1975, Day 1975, Prakasam 1974, and Loehr 1973). These summary papers include the theory of removal mechanisms, predictive and design equations, and virtually all information needed for oxidation ditch assessment. The large data base is in contrast to the fact that less than 0.2 percent of all swine waste is treated in this manner.

In overview, the use of oxidation ditch pretreatment has evolved into three categories of treatment strategy: odor control, nitrogen removal, and nitrogen conservation. These alternatives require three levels of oxygen input and hence, increasing costs (Kroeker 1975). For each pretreatment strategy there are two major operational modes: 1) continuous operation until the ditch is full and then empty, or 2) continuous operation with ditch filling and overflow until solids buildup requires emptying. These operations have an effluent concentration difference in the short term but similar effluent yields on an annual basis. Summarizing the overall oxidation ditch technology, it appears that: 1) nitrogen removal can be made very efficient, 2) there are cold region applications in which the principal goal is odor control and storage, but that alternative odor control technologies should be considered to achieve the best long range economic solution, 3) the oxidation pretreatment does not yield effluent which is amenable to stream discharge; hence, land is the receiver, and 4) the cost and energy requirements are high. Trends in the farm scale use of oxidation ditches are difficult to assess and will be highly dependent on energy and maintenance costs.

Design of oxidation ditches involves specification of the input waste load, the oxygen transfer needed for the employed pretreatment strategy, and the configurational parameters of ditch length and volume. The recommended ditch volume is $0.18 \text{ m}^3/45\text{-kg hog}$ (Midwest Plan Service 1975). For odor control (Kroeker 1975) the oxygen transfer should equal the carbonaceous demand of the waste input, Table 40, or $0.3 \text{ kg O}_2/\text{d}/45\text{-kg hog}$ and with the recommended oxygen transfer for oxidation ditch rotors (Midwest Plan Service 1975) of $0.86 \text{ kg O}_2/\text{kwh}$ about $0.015 \text{ kw}/45\text{-kg hog}$ would be required. As a point of comparison, the power requirements providing the same daily oxygen input for odor control in mechanically aerated lagoons (measured O_2 transfer = $1.3 \text{ kg O}_2/\text{kwh}$) would be $0.0095 \text{ kw}/45\text{-kg hog}$, or 35 percent lower.

In order to achieve maximum nitrogen removal both the carbonaceous and nitrogenous oxygen demand must be supplied. With 3.57 g O_2 required per gram of ammonium ion converted to nitrate (Kroeker 1975), the oxidation ditch nitrogenous power requirements are $0.0016\text{-}0.0032 \text{ kw}/45\text{-kg hog}$.

Table 40. OXIDATION DITCH REQUIREMENTS FOR SWINE WASTE

Oxidation ditch strategy	Oxygen requirements g O ₂ /d/45-kg hog	Power requirements, (assuming 0.86 kg O ₂ / kwhr), kw/45-kg hog
Odor control	300	0.015
Nitrogen removal	332-364	0.016-0.018
Nitrogen conservation	332.01-364.01	0.016-0.018

Total oxidation ditch requirements are about 0.017 kw/45-kg hog depending on the degree of TKN conversion. This is only slightly greater than the odor control power requirements. Operation at this level of oxygen input should result in no dissolved oxygen in about 50 percent of the ditch and thus a good environment for denitrification. The third alternative ditch operation is to maintain continuously a dissolved oxygen level of greater than 2 mg/l throughout the ditch. Additional inputs for this are less than 0.1 percent above the power inputs of 0.017 kw/45-kg hog.

Oxidation ditch performance may be determined in a number of ways depending on whether the operation is a batch or continuous unit. The concentration of effluent can be that of the mixed liquor with continuous overflow, the mixed liquor with solids buildup until a critical level requires emptying, or as an effluent which has been clarified after overflow from the ditch. These differences are very much producer related and exhibit short term variations. However, if it is recognized that on a long term all constituents not stabilized or lost as gaseous products must be handled then the material requiring land application for this pretreatment alternative can be determined.

Total nitrogen losses have been reported for oxidation ditches, Table 41. A differentiation between operation for odor control or maximum nitrogen removal was not made in these reports, so that corresponding nitrogen losses were difficult to assess as a function of treatment strategy. However, one study on poultry manure was found in which operation for odor control resulted in about 50 percent nitrogen removal which, as expected for a system with little nitrification and only ammonia losses, was lower than the nitrification-denitrification operations (80 percent reduction). Oxidation ditch effluent nitrogen levels were determined from these percentage losses while cation and metal species were considered conservative with respect to the total long term operation, Table 42.

The organic removal or stabilization for oxidation ditches has been evaluated by means of COD, BOD₅, TS, and VS, Table 41. Mixed liquor concentrations are given in Table 41, as well as representative effluent concentrations following clarification. Percentage removals from reported mass balance results and from ratios of the mixed liquor concentration to influent concentration were in agreement and were used to determine the long term effluent amounts for oxidation ditch pretreatment, Table 42. It should be noted that even with clarification the effluent is not suitable for stream discharge.

Table 41. OXIDATION DITCH TREATMENT OF SWINE WASTES

Reference	Loading rate, m ³ /45-kg hog	Oxidation ditch mixed liquor concentration, mg/l			Percent loss of constituents, %				
		COD	BOD ₅	TS	TN	COD	BOD ₅	TS	VS
Talpanides 1972	1	6,000-12,000	1,000-4,000	8,000	--	--	80	--	--
Terwilliger 1975 (odor control)	1.6-3.2	--	--	--	--	69	70	65	74
Day 1971	6-10	12,000	3,000	12,000	--	--	90	--	50
Jones 1969	8.4	--	--	--	--	--	--	--	50-55
Scheltinga 1966	10	--	--	--	--	--	96	--	--
Windt 1971	10	15,000	1,500	15,000	--	60	90	53	--
Day 1969	11	6,000	3,000	10,000	--	--	--	--	--
Smith 1971	12	--	--	--	80	75	--	80	--
Mulligan 1972	12	--	--	--	--	59	55	--	78
Jones 1972	29	12,000	3,000	12,000	80	90	100	--	--
Foree 1969	30	--	--	--	--	--	93	--	--
Kroecker 1975 (odor control, poultry manure)					50	45	--	--	--
Value judged most reliable					80	75	90	65	75
Oxidation ditch with clarifier									
Scheltinga 1966	10	550	15	--					
Smith 1971	12	500-1,000	50-150	--					
Jones 1972	29	2,750	--	--					

Table 42. APPROXIMATE PRETREATMENT PERFORMANCE OF OXIDATION DITCHES
FOR SWINE WASTES WITH INPUT DEFINED IN TABLE 25

Parameter	Effluent, g/d/45-kg hog
Nitrogen-removal strategy	3.5
Nitrogen-odor control	9
Phosphorus	6
Potassium	8
Sodium	2
Calcium	9
Magnesium	2
Copper	0.02-0.2
Zinc	0.14
Manganese	0.055
Chloride	14
Chemical oxygen demand	75
Biochemical oxygen demand (BOD ₅)	12
Volatile solids	45

Overland Flow (OLF)

The promotion of controlled runoff from the application of wastewater and subsequent effluent collection represents a pretreatment for swine wastes. A schematic of a typical overland flow system is presented in Figure 23. In such systems more than half the applied wastewater is available as runoff for reuse or terminal land application. This effluent is reduced in the various influent waste constituents with the mechanism and efficiencies or removal being dependent on the specific parameter. No performance reports were found for OLF pretreatment of swine wastes, but two references for swine lagoon effluent applied as OLF were reported (Sievers 1975 and Humenik 1975). To supplement these data, it was felt that the waste type was relatively less important in delineating the mechanism and removal percentages hence, 5 additional agriculturally related wastes and 6 municipal systems were used to estimate overland flow pretreatment of swine waste. (Stevens 1969, Mather 1969, Bendixen 1969, Locke 1972, Walker 1972, Witherow 1973, Carlson 1974, Thomas 1974, Myer 1974, Brack 1975, Overcash 1976 a).

The mechanism of stabilization and removal for organic and nitrogen inputs has been discussed with respect to microbial pathways (Carlson 1974). In overview, organic solids are initially removed by filtration, settling, and soil sorption. Between waste applications, the soil microbial zone interfacing the atmosphere becomes aerobic and thus initially removed material is aerobically stabilized.

Net system removal of nitrogen involves ammonia volatilization, nitrification-denitrification (in the flowing liquid and/or in the cyclic loading and rest periods), soil infiltration, and plant uptake. The relative magnitude of these pathways have not been well established. Phosphorus removal is primarily by sorption and soil complex formation. With respect to cations and heavy metals, few data are available especially on the critical question of OLF pretreatment longevity. Initial removal of cations by the soil surface has been demonstrated but the capacity of this zone for long term removal is not known (Sievers 1975 and Thomas 1974).

The capacity of OLF to effect substantial pathogen dieoff has been demonstrated (Thomas 1975); presumably because of the basically aerobic system, the cyclic drying, and the competition with existing soil microorganisms. Odor reduction was proposed as a potential advantage of OLF (Thomas 1975). The frequent, low application procedure maintains aerobic surface conditions and provides odor control.

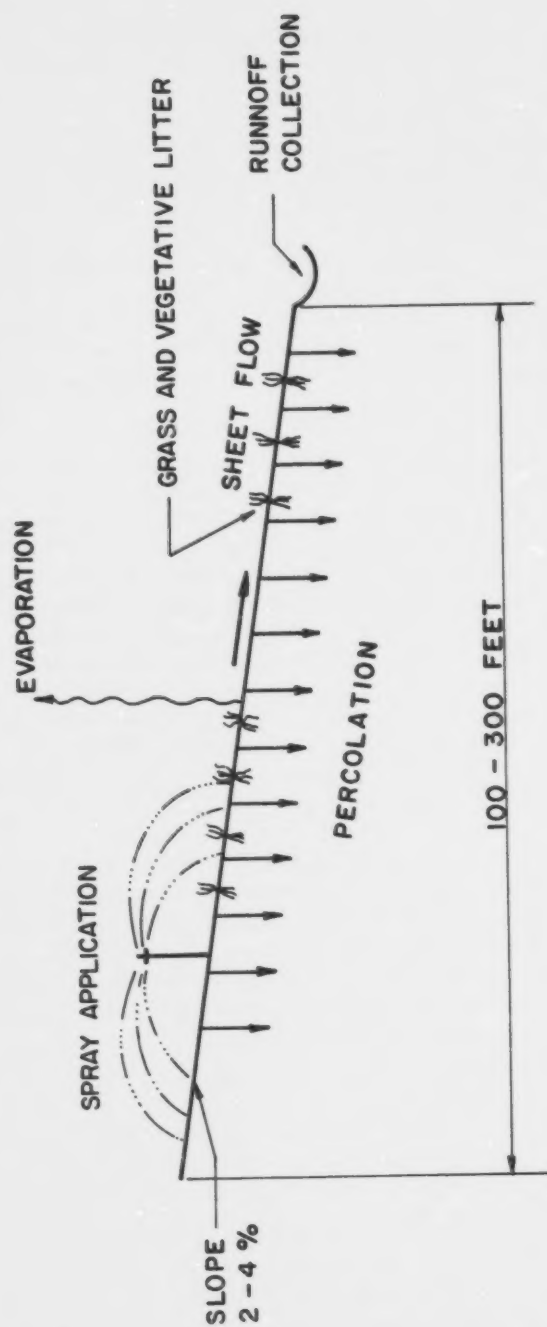


Figure 23. Schematic of OLF pretreatment process.

OLF pretreatment was judged from the data for a variety of systems. The differences in performance were not large (Overcash 1976a). It should be noted, however, that design variables for OLF can be manipulated to produce effluent concentration changes but these are not specified in this state-of-the-art review. The average OLF system is 10-40 m in flow distance and can receive anywhere from 1-15 cm/week of liquid. Ground-level applicators (e.g. gated pipe) or conventional sprinkler systems have been used to apply the wastewater to the upper portion of OLF systems. Animal waste must be diluted for successful treatment by OLF, hence, it is compatible with flushing operations in which substantial additional water is used for waste transport. Following the OLF with a lagoon system permits recycle of water for flushing thereby greatly reducing fresh water inputs. Lagoon monitoring for cation constituents signals when critical toxic levels of one or more species are reached and irrigation outside the OLF system is required. Recharge with fresh water allows safe continuation of the OLF system.

Percentage removal for total nitrogen was evaluated to be approximately 85 percent while BOD₅, TSS and P were 95 percent, 95 percent, and 40 percent, respectively. Research results for COD and TOC were not available and hence, were assumed equal to that for BOD₅. Wastes from slatted floor-pit or concrete slab facilities and swine dry lots were evaluated as potential influent sources for OLF. The former would be similar to municipal or food processing systems and the latter similar to effluents from grassed buffer zones or the switch back runoff pretreatment facility proposed for beef feedlots (Swanson 1975). The percentage of constituents remaining after OLF and analogous input amounts were used to evaluate OLF pretreatment, Table 43. Cations were not included in Table 43 because of the previously discussed data gap on long term performance.

Research is needed to assess the performance potential and economics for swine waste nitrogen removal by means of OLF. A total system of OLF, lagoon recycle and periodic land application would appear to produce high levels of nitrogen pretreatment. The long term system efficiency with respect to cations merits research since the quality of effluent for terminal land application is critical in moisture-deficit regions.

Table 43. APPROXIMATE PRETREATMENT PERFORMANCE OF OVERLAND FLOW SYSTEMS RECEIVING SWINE WASTES FROM CONCRETE SLAB OR SLOTTED FLOOR-PIT UNITS, TABLE 25, AND FROM DRYLOT PRODUCTION UNITS, TABLE 28

Parameter	Effluent, g/d/45-kg hog	
	Input-concrete slab or slotted floor-pit unit raw waste	Input-drylot runoff
Nitrogen	2.7	0.15
Chemical oxygen demand	15.0	0.80
Biochemical oxygen demand (BOD ₅)	6.0	0.30
Total organic carbon	4.0	0.20
Total suspended solids	9.0	0.45
Phosphorus	3.5	0.20

PRETREATMENT PROCESSES ORIENTED TOWARD PARTIAL REUSE

High Rate Anaerobic Digestion-Methane Production

Swine waste digestion represents a pretreatment process in which some recovery or utilization value is obtained. Methane is formed under anaerobic conditions from swine waste organics with the rate of production dependent on the waste loading rate. High rate, heated digesters for swine waste have similar microbial transformations, but greater rates and efficiencies of gas production than anaerobic lagoons. The consideration of high rate methane production from animal wastes has been widespread and a number of good reviews of the biochemistry, production efficiency, and operation are available (Smith 1973 and Jeffrey 1963). Additionally, a recent excruciatingly complete bibliography and data summary (Shaddock 1975) has become available. These reports and the similarity to anaerobic lagoon pretreatment obviate the need for a detailed mechanistic discussion in this report.

The major differences in the fermentation of swine waste constituents in digesters versus lagoons is due to the enclosed, small volume construction of digesters. Nitrogen removal by ammonia volatilization is virtually eliminated with controlled methane reactors. This is a distinct advantage because all the fertilizer value is retained, as well as extracting fuel value from the organic fraction. The low reactor volume per hog and the use of mixing or heating with high rate digesters means that there is little opportunity for sludge accumulation. Therefore, cations or metals which would settle are periodically removed from the digester and therefore, represent the total effluent. These elements are conservative; and hence, the methane generator as a pretreatment alternative does not alter the amount of cations or metals as generated in the swine production unit waste loads.

With respect to organic stabilization, the reduction in volatile solids and COD for a number of digesters was determined to be about 47 percent and 42 percent, respectively (Midwest Plan Service 1975). Reduction of TOC was approximated from the average gas generation value of 1.8 m³/d/1,000 kg animal (Midwest Plan Service 1975) and the carbon content of the gas as 48 percent. BOD₅ reduction is judged to be similar to COD or about 42 percent. Assuming these percent reductions for carbonaceous compounds and total conservation of other constituents, yields the performance of high rate digesters or methane generation as a pretreatment for swine waste, Table 44.

Table 44. APPROXIMATE PRETREATMENT PERFORMANCE OF METHANE DIGESTERS
RECEIVING SWINE WASTES, TABLE 25

Parameter	Effluent, g/d/45-kg hog
Nitrogen	18
Phosphorus	6
Potassium	8
Sodium	2
Calcium	9
Magnesium	2
Copper	0.02-0.2
Zinc	0.14
Manganese	0.055
Chlorine	14
Chemical oxygen demand	175
Biochemical oxygen demand (BOD ₅)	70
Total organic carbon	47
Volatile solids	95

Solids Separation

The physical separation of a portion of the solid material in swine waste can be accomplished by a variety of conventional devices. In terms of waste management, the objectives of a solids separation process are: 1) to recover organic solids for reuse in such processes as refeeding, methane generation, pyrolysis, composting, etc., 2) to reduce total solids and thereby facilitate pumping and handling, and 3) to reduce the solids prior to processes adversely affected by clogging such as ion exchange, reverse osmosis, etc. As with other pretreatments, solids separation can be evaluated with respect to the change in waste constituents.

Mechanisms for solids removal are dependent on two general principles. The first is the physical dimensions of the solid particles which dictate whether or not a particle will pass through an opening of defined size. Those which do not pass the opening are separated from the bulk of the liquid. In this group of separators, swine waste studies have been reported for the vibrating screen (Ngoddy 1971), the stationary screen (Shutt 1975), the rotating drum filter (Glerum 1971), other filter arrangements (Hepherd 1975), and the centrifuge (Glerum 1971).

The second solids separation principle is based upon phase separation by specific gravity resulting in a solids zone and a clarified liquid. These zones can be withdrawn selectively and the phase separation accomplished. Settling can occur with normal or elevated gravitational fields with the latter improving the rate and efficiency of separation. In this category, swine waste separation has been reported in the upflow settling chamber with a variety of detention times (Fischer 1975, Shutt 1975, Jett 1973, Wong-Chong 1975, Glerum 1971), centrifuge (Guidi 1971), decanter centrifuge (Jones 1972 and Glerum 1971), rotated flighted cylinder (Miner 1975b) and hydrocyclone (Shutt 1975). The equipment for these solids separation modes are well illustrated in several sources (Midwest Plan Service 1975, Glerum 1971, and Shutt 1975).

The separation of solids (evaluated by TS, VS, COD, BOD₅, and crude protein, etc.) also brings about the removal of nitrogen. Organic nitrogen removal proceeds as the solids removal; but in addition, ammonia is separated by weak absorption to organic matter and by the physical entrapment of liquid with the solid fraction. The degree of ammonia separation is highly dependent on the particular device and operational characteristics. Several studies have monitored nitrogen separation (Ngoddy 1971, Hepherd 1975, and Fischer 1975), but no distinction or explanation of the ammonia-organic nitrogen relation is currently available.

Removal of phosphorus and various cations during solids separation has been monitored, but the mechanisms for these species removal are speculative. The quantity incorporated in biomass or plant tissue is small. Chelates or other tightly bound complexes of Cu, Zn, and Mn with organic matter assist separation in anaerobic lagoons (Overcash 1976) and correspondingly, would be expected to contribute to removal in raw swine waste separation processes. It is anticipated that other species such as K, Na, and Ca which are less tightly bound to organics would be less affected during solids separation. The behavior of precipitates (MgNH_3PO_4 , Booram 1973) in swine waste separation is not presently known. The physical retention of liquid in the solids fraction leads to apparent cation removals as was also noted for ammonia.

Solids separation also reduces swine hair thus improving waste handling properties. No data were found on microbiological or pathogen removal occurring with swine waste separation by any device.

The performance of various solids separation devices for swine waste were arranged according to efficiency of dry matter removal, Table 45. The physical screening of material appears to be less efficient than the settling class of devices. One exception is the high efficiency obtained with a filter-settling chamber combination (Hepherd 1975).

As anticipated, the removal of solids was more efficient as the opening, through which the swine wastes were forced, decreased with an upper limit at about 50 percent removal. Since data are limited, comparisons of efficiency among the various size classifying devices was not possible. As a general estimate, it appears that the opening size is the predominant factor regardless of the particular device, Table 45. COD and N removals were not always consistent, but generally followed TS reduction. COD and N data were not as complete and with N there were confounding factors such as ammonia absorption and physical carryover of liquids with the solid fraction. If effective separation is obtained (opening size less than 1 mm), the screen devices yield a TS removal of about 40 percent whereas the vacuum filters yield about 50 percent removal. Based on limited data, the COD and N removals in the solid fraction for the size-type separators were approximately 30 percent and 55 percent, respectively.

The gravity settling type devices produced a separation of 65 percent-85 percent for TS while use of centrifugal force increased solids separation to about 90 percent. COD and N removals which are not well documented are estimated to be 60 percent and 45 percent, respectively, for settling chambers and possibly up to 90 percent with centrifugal force (greater than 1,000 g).

Table 45. SEPARATION PERFORMANCE OF VARIOUS DEVICES RECEIVING RAW SWINE WASTE

Reference	Device	Opening size fraction	Percent removal from influent, %								
			DM	COO	N	P	VS	Ca	Mg	K	Na
Shutt 1975	stationary screen	1.5 mm hole	3-10	10-24	--	--					
Shutt 1975		1.0 mm	10-25	50-70	--	--					
Hgoddy 1971	vibrating screen	0.25 mm	33	26	59	58	58	58	58	52	
Hgoddy 1971		0.15 mm	39	29	58	--					
Hgoddy 1971		0.075 mm	40	30	58	--					
Hgoddy 1971		0.044 mm	42	35	61	--					
Glerum 1971	centrifuge	0.03 mm	55	28	--	--					
Hepherd 1975	rotating vacuum drum filter	0.2 mm	46-53		26	10	26	21	16	20	
Glerum 1971	rotating vacuum drum filter		51	--	--	--					
Fischer 1975	settling chamber		55-60	50-60	40-60	30-50	55-70				
Shutt 1975	settling chamber		--	55	--	--					
Hong-Chong 1975	settling chamber		84	--	33	89					
Glerum 1971	settling chamber		85	75	--	--					
Hepherd 1975	filter-settling chamber		81	--	45	100	86	62	56	50	
Guld 1971	centrifuge		90	90	--	--					
Jones 1972	centrifuge (decantar)		96	96	95	94					
Glerum 1971	centrifuge (decantar)		65	52	--	--					
Fischer 1976	VS - 55-70%										
Hgoddy 1971	Zn-55%, Cu-49%, Mn-57% Fe-60%										
Jett 1973	Crude protein-17%, ether extract-7% ash-13%, nitrogen free extract-32%										

Phosphorus removal is not well documented, but the settling chamber devices would be expected to reach removals associated with anaerobic lagoons of approximately 90 percent (Humenik 1976). Such high removals would not be anticipated for screen separators since about 70 percent of the total phosphorus is loosely bound (ortho-phosphorus) which is easily solubilized and thus carried with the liquid fraction (Howell 1976). The remaining swine constituents are listed in Table 45, but reliable estimation of percent removal is not currently justified. For Ca, Mg, K and Na, the Ca removal with the solid fraction were usually larger than other cations which qualitatively agrees with lagoon removal trends. However, the similarity among these parameters and the similarity to Cu, Zn, and Mn (more tightly bound to organics) indicates that possibly the liquid carryover is significant. A fixed percent of liquid removed would appear as a constant percent extraction for all cations and might mask any variation due to chelated or bound materials.

Translation of the percent removals into the pretreatment effect on the amount of the various defecated waste constituents was performed, Table 46. These data are for the liquid effluent stream, but in some instances the solids fraction might be considered as the effluent or least desirable fraction. The solids stream can be obtained as the difference between values in Tables 25 and 46. Future research emphasis should be on target waste constituents, e.g. N and cations rather than TS. In addition, a uniform economic evaluation is greatly needed since reported data are highly variable and usually include only investment or power costs. If the pretreatment objective(s) of solids separation are defined, the data in Tables 45 and 46 will aid in selecting the type of device which will produce the desired separation.

Pyrolysis

The pretreatment of animal waste by thermochemical processes has been investigated by several groups in which various aspects of inputs and effluents have been reported (White 1971a, Corvino 1975, Nelson 1975, and Appell 1971). Pyrolysis is a thermochemical process in which waste is chemically decomposed in a closed system at elevated temperatures ($200^{\circ}\text{C} - 800^{\circ}\text{C}$). Three product or effluent streams are produced, 1) a solid fraction termed char or residue, 2) a gas fraction which when condensed is an oil or fuel, and 3) a gas fraction which when condensed is aqueous in nature. All three streams can be used as products, Figure 24. Generally, the char and oil are recycled completely while the aqueous stream would be most feasibly applied to the land. Thus, from the pretreatment perspective, the aqueous portion is the pyrolysis effluent. The char is a second possible effluent for land application and has been investigated in this regard for poultry manure (Nelson 1975). The char was acceptable for land application if proper design for salt limitation was used. An excellent discussion of the implications of pyrolysis for poultry operations which can be readily related to swine wastes is available (Nelson 1975).

Table 46. APPROXIMATE PRETREATMENT EFFECT OF SOLID SEPARATION DEVICES RECEIVING SWINE WASTES,
AS DETAILED IN Table 25

Parameter	Liquid effluent, g/d/45-kg hog		
	Size separator class	Gravitational separator class	Centrifugal separator class
Nitrogen	8	10	2
Chemical oxygen demand	210	120	30
Total solids	90-110	30-90	20
Phosphorus	--	0.3	--
Cations	highly contingent on individual device design and operation		

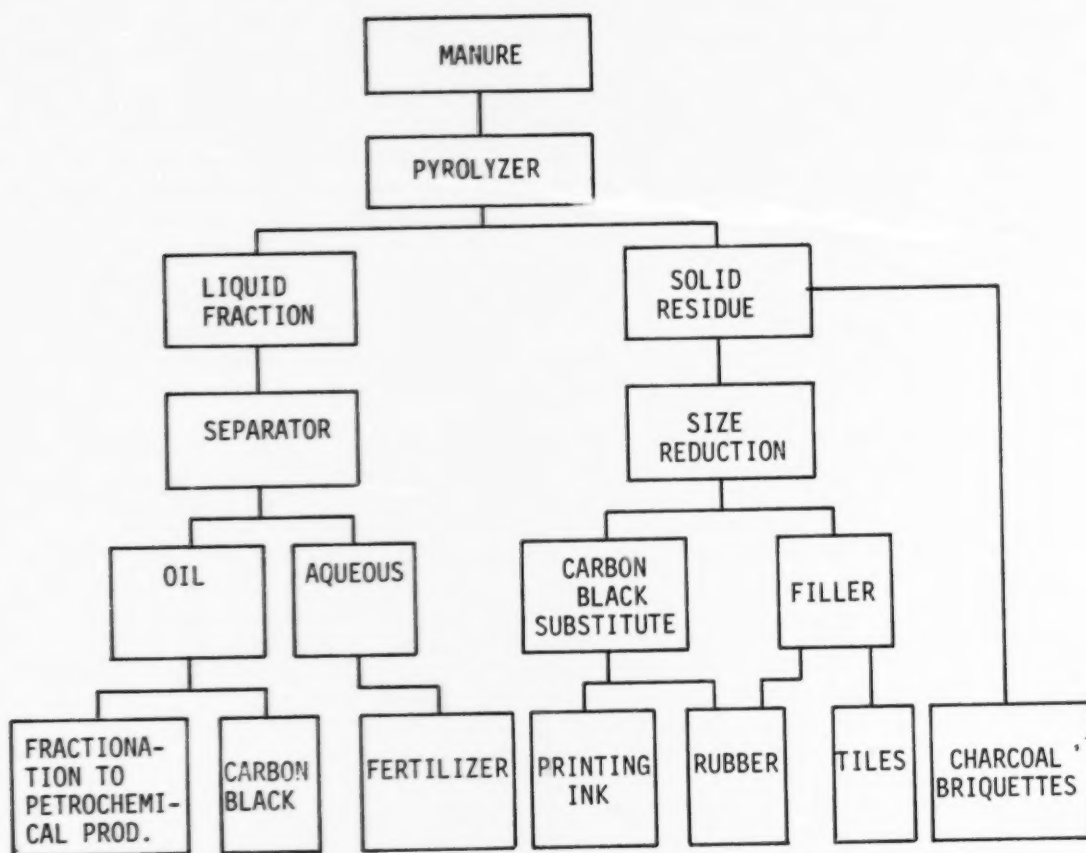


Figure 24. Pyrolysis process streams and potential end uses for terminal wastes (Corvino, 1975).

A related process to pyrolysis is hydrogenation in which manure is heated under pressure in the presence of carbon monoxide, steam, and a catalyst. Similar product streams are produced and one demonstration for animal waste was reported in the literature (Appell 1971). The costs and optimal conditions for pyrolysis and hydrogenation have not been well documented for swine wastes; therefore, the limited performance data are extrapolated from available animal waste information. These thermochemical processes represent a very high level of utilization or recycling of animal wastes.

Data were extracted and calculated from the four reports concerning animal waste in order to derive mass balances. Since this overall approach was not previously reported not all the data sources were totally inclusive and assumptions especially regarding the constituent content of the input were necessary. From available sources including data for hydrogenation, assessments of TS, N, and C were made, Table 47. A limited reference (Corvino 1975) was also included although it consistently differed from the other data, possibly because of the lower temperature employed or the method of data reporting. It should be noted that the percentages listed are approximations and represent a number of operating and experimental conditions.

Considering the aqueous portion as the pretreatment process effluent, the fraction of the initial solids remaining in the effluent is about one-third. However, if wet manure is pyrolysed the water portion is nearly one hundred percent recovered thus increasing the effluent volume. About 40 percent of the nitrogen and 25 percent of swine waste carbon would be in the aqueous effluent. The estimation of effluent amounts of phosphorus, potassium, various cations and heavy metals has not been well documented. Pyrolysis temperature would be critical since elements are vaporized in varying and substantial amounts above approximately 600° C. Pyrolysis and hydrogenation at low temperatures, 200° C to 500° C (Corvino 1975 and Appell 1971) result in very little nonorganic vaporization and incorporation into the aqueous effluent. However, pyrolysis processes operated between 600° C and 800° C (Nelson 1975 and White 1971a) would cause volatilization of phosphorus, potassium, etc., but the extent and percentage cannot be defined a priori. The relative merits of concentrating various metals in the char of aqueous phase is dependent on the end use of these products and warrants further study.

Applying the percentage removal to the swine waste generation rates, the pretreatment performance of pyrolysis can be established, Table 48. The limited data base for this calculation should be noted.

Table 47. SEPARATION OF WASTE CONSTITUENTS FROM ANIMAL WASTES BY PYROLYSIS PROCESS

Constituent	Reference	Percentage of constituent waste input in effluent streams, %		
		Char	Oil	Aqueous
TS	White 1971a (swine, poultry, beef and dairy)	30-40	40-60	10-30
	Corvino 1975 (cattle)	34-58	1-8	22-35
	Nelson 1975 (poultry)	20		
	Appell 1971 (bovine-hydrogenation)	12	38	
	Value judged most reliable	30	45	25
		10-20	50	30-40
N	White 1971a			3.5
	Corvino 1975			
	Nelson 1975			
	Appell 1971			
	Value judged most reliable			
C	White 1971a			
	Corvino 1975			
	Nelson 1975			
	Appell			
	Value judged most reliable			

Table 48. APPROXIMATE PRETREATMENT PERFORMANCE FOR PYROLYSIS
OF SWINE WASTES, BASED ON WASTE GENERATION IN
TABLE 25

Parameter	Effluent, g/d/45-kg hog
Nitrogen	7
Total solids	60
Carbon	25

Refeeding Processes

As a utilization pretreatment, the direct refeeding or the processing of wastes prior to refeeding yields direct benefits in waste reduction and in reducing the principal cost of animal production-feed. The applicability of refeeding is based on the similarity of chemical composition (amino acids, minerals, etc.) between waste and commonly employed feeds. However, other waste constituents, often introduced into feeds, impose refeeding limitations because of recycling buildup, e.g. heavy metals hormones, etc. An additional concern is the potential for disease transmission. Suggested techniques for overcoming these limitations (Harper 1975) include dispersion of wastes to animals not producing waste for recycling, waste dilution using feeds with lower concentrations of critical constituents, and extraction or conversion of limiting constituents from manure prior to refeeding.

The predominance of the research and farm scale application of refeeding processes has been in the beef and poultry industry. Beef waste is attractive because of the point source density and the fibrous, high solids content. Processing of beef wastes for refeeding has involved drying, ensilage, separation and partial reuse, and fractionation with full recovery. Reviews of the processes are available (Harper 1975, Midwest Plan Service 1975, Anthony 1971, and Yeck 1975). Poultry manure or litter have been demonstrated and evaluated as feed for beef cattle and other animals (Fontenot 1966, Flegal 1972, and Creger 1973). Wide-spread interest currently exists for ensiling poultry litter and refeeding to ruminants. The high nitrogen to carbon ratio of poultry waste emphasizes the refeeding advantages of poultry waste or processed poultry wastes (Midwest Plan Service 1975).

Swine waste refeeding processes are less advanced from a research-demonstration standpoint although interest is increasing. The overall characterization of swine waste has been expanded. Refeeding parameters such as crude protein, ether extract, etc., Table 23, and amino acid distribution, Table 49, depicting refeeding potential have been documented. However, field techniques for treating high moisture content manure, using the soluble versus solids fraction, and selecting the most advantageous preprocessing scheme for refeeding have not been developed.

Refeeding results for dry swine feces with percentage substitution of feces between 10 percent and 40 percent to swine have been obtained (Diggs 1965, Orr 1971, and Holland 1975). With the exception of a 15 percent substitution (Diggs 1965) the digestibility and feed efficiencies were depressed by approximately 10 percent-20 percent below the normal ration. Studies comparing wet feces versus dry feces as a fraction of the feed showed no difference in digestibilities or mineral retention

Table 49. AMINO ACID CONTENT OF SWINE FECES AND SWINE OXIDATION DITCH MIXED LIQUOR AS RELATED TO REFEEDING POTENTIAL

	Gouwens 1966	Orr 1971	Day 1975 (Oxidation ditch mixed lagoon)
Phenylalanine	0.81	0.87	1.48
Lysine	0.60	1.11	1.42
Histidine	0.14	0.40	0.47
Arginine	0.44	0.67	1.28
Threonine	0.53	0.80	1.96
Valine	0.58	1.04	2.06
Isoleucine	0.52	1.03	1.49
Leucine	0.92	1.57	2.79
Aspartic		1.37	3.73
Serine		0.58	2.55
Glutamic Acid		3.37	5.06
Proline		0.91	1.29
Glycine		1.51	2.29
Alanine		1.14	2.83
Cystine		0.12	
Methionine		0.58	0.77
Tyrosine		0.65	1.17
Tryptophan			0.28

by the test swine (Holland 1975). Swine oxidation ditch mixed liquor was used as drinking water for swine with the result that gain and feed efficiency values were improved (Harmon 1973). The investigators indicated that the beneficial effect was probably the addition of certain amino acids or trace elements since the nutritive value of this liquid was very low. Research results for feeding dried swine feces to rats (Eggum 1974) and to sheep and cattle (Pearce 1975) also evidenced lower digestibility than the unsubstituted ration. The decreased digestibility and conversion efficiency for refeeding swine waste which results in longer growing periods are offset economically by the low cost associated with waste material used as feed. This is especially true for use of manure "as is" since processing by drying or fractionation significantly increases cost.

Viewed as a pretreatment process, refeeding swine wastes represents a reduction in the overall amount of various constituents depending directly upon whether any of the material is removed by the animal receiving the recycled manure. If as shown for several elements, there is no retention by the animal then the total amount of these elements which must ultimately be land applied is the same. Research in Virginia (Holland 1975) has described quantitatively the changes in feces and urine content of swine receiving 0 percent, 22 percent, and 37 percent (d.m.b.) of the ration as swine feces. The fecal content of crude fiber, ether extract, crude protein, magnesium, copper, and zinc increased as the feces in the feed increased, while the ash, nitrogen-free extract, calcium, phosphorus, and potassium were constant. However, to calculate the amount of the various constituents taken up by the animal in the second feeding, the mass of feces excreted after first and second feeding would be needed. Data indicate that at 22 percent and 37 percent feces in the ration the wet feces output was 196 percent and 254 percent, respectively, of the no feces ration while the urinary output and feed intake were the same. On a mass balance basis, this would indicate an inconsistency of constituent generation during refeeding. Possibly the solids content (not reported) was greatly reduced with the feces substitution or there were some short term factors affecting the experiment.

In summary, sufficient data are not available to completely assess the effect of refeeding swine feces to swine or other animals on the basis of waste constituent amount (g/d/45-kg hog). Available qualitative information indicates that portions of the organic and mineral content of swine waste are available to the animal and therefore, refeeding has a pretreatment effect of reducing the total effluent from swine production. Research to quantify the pretreatment effect is needed as well as to evaluate the potential, techniques, and hazardous limitations of this technology.

PRETREATMENT PROCESSES ORIENTED TOWARD NEARLY COMPLETE RECYCLING OR REUSE OF SWINE WASTES

Composting

The process of composting is basically an aerobic treatment occurring in the thermophilic temperature range (70°C). The more conventional system involves waste products in a solid, low moisture form in which oxygen diffusion from the air is augmented by windrowing the solids or blowing air through the stack. Such a system requires less energy than a liquid phase reactor to input the needed oxygen and takes advantage of exothermic biological activity to attain the thermophilic regime (Midwest Plan Service 1975). Recently data have been reported for animal waste composting in the liquid phase (Grant 1975 and Terwilleger 1975).

The mechanism for pretreatment reduction of nitrogen in composting swine waste involves several pathways. Nitrate formation and subsequent denitrification, when all or a portion of the compost turns anaerobic, appears to be a principal mechanism when large losses of N are observed (Stombaugh 1975). However, nitrogen can be conserved by prevention of anaerobiosis. Under these conditions, the principal loss mechanism is ammonia volatilization. In the liquid composting systems, the N loss pathways are not well defined, but nitrification-denitrification potential exists as well as some volatilization from the large foam layer which builds at the liquid surface. Additional factors having a lesser effect on N loss are C/N ratio (University of California 1953), presence of superphosphate, nature of carbon substrate, and windrow configuration (Willson 1975, Stombaugh 1975, and Wong-Chong 1975).

For swine waste parameters such as phosphorus, potassium, cations, and heavy metals, the composting process provides no pretreatment removals. The only effect anticipated would be some concentrating of these species as volatile solids are lost from the system. The exception is composting in open piles which is both less efficient and because of precipitation input leads to drainage and potential loss of soluble ions and compounds.

Carbonaceous constituents are readily removed by the aerobic composting process through microbial conversion to carbon dioxide and water. These losses are substantial and result in waste volume and weight reduction. The aerobic environment leads to odorless operation due to the nature of endproducts of the predominant microorganisms. Pathogen dieoff or inhibition of most species is also accomplished with these thermophilic processes (Midwest Plan Service 1975).

From limited data, Table 50, the losses of nitrogen are approximately 25 percent of the raw waste input. The higher loss of 70 percent was for a system (Stombaugh 1975) in which waste is treated aerobically and then

Table 50. LOSSES OF SELECTED CONSTITUENTS OF ANIMAL WASTE DURING COMPOSTING OPERATIONS

Reference	Waste type	Carbon: Nitrogen ratio	Constituent loss, % of input		
			N	VS	COD
Stombaugh 1975	Swine	5-15	70	75-89	
Willson 1975	Dairy	13-30	20-26	17-28	22-40
Singley 1975	Swine	10-15	0-20		
Wells 1969	Cattle		low	30	
Martin 1972	Swine	12	16-50	25	

as more wastes are added, a lower anaerobic storage zone is developed. A nitrogen loss of 58 percent was also reported for a compost which was periodically anaerobic and aerobic (Willson 1975). Depending on the system design, a wide range of N losses can occur; however, since the major end use is land application, those systems with nitrogen conservation may be the most beneficial and were selected as the representative and achievable effluent. For the aerobic system, the VS and COD losses were assumed to be about 30 percent. These percent losses can be applied to the swine waste generation rate to establish the amount of various species leaving the composting process, Table 51.

WASTE PRETREATMENT UNIT PROCESS-SELECTION AND COMPARISON

Total waste management systems necessarily include the production unit, the intermediate pretreatment process(es), and the terminal receiver. The most cost-effective terminal receiver for swine waste is the plant-soil system. Critical design factors for land-based systems are nitrogen, and salts in moisture-deficit regions because these swine waste components limit land application rates. Pretreatment processes are devices or technologies which can operate singly or in combination (in series or parallel) to allow more convenient handling or reduce limiting constituents levels so that more waste can be safely applied to a unit area. The decision on which pretreatment process to recommend depends primarily on the economics of alternative systems which are environmentally acceptable.

Technically, the major challenge is to balance the waste load with the available land. If land is not limiting, then pretreatment may consist of convenient handling and storage units with maximum conservation potential. However, if sufficient land is not available to assimilate all waste constituents, then the least cost pretreatment process to reduce critical constituent levels to land assimilation capabilities becomes the predominant factor. Hence, there is a critical need to understand the comparative capability of pretreatment unit processes to reduce the nitrogen and cations or salt content.

Nitrogen-Based Comparison

An initial comparative assessment of pretreatment alternatives was made by listing the unit processes previously described according to effluent nitrogen content, Table 52. Pretreatment processes having at least 70 percent retention of the defecated nitrogen load would comprise the nitrogen conservation alternatives. As the value of swine waste nitrogen increases, the least cost total system will favor selective pretreatments that conserve nitrogen; high rate methane digestors, composting, high loading rate lagoons, and direct land application.

Table 51. APPROXIMATE PRETREATMENT PERFORMANCE OF COMPOSTING RAW SWINE WASTE, BASED ON TABLE 25

Parameter	Composted effluent, g/d/45-kg hog
Nitrogen	14
Phosphorus	6
Potassium	8
Sodium	2
Calcium	9
Magnesium	2
Copper	0.02-0.2
Zinc	0.14
Manganese	0.055
Chloride	14
Chemical oxygen demand	210
Volatile solids	125

Table 52. COMPARISON OF PRETREATMENT PROCESSES FOR SWINE WASTES BASED ON REMOVAL EFFICIENCY FOR NITROGEN

<u>Production unit or pretreatment process</u>	<u>Effluent amount of nitrogen, g/d/45-kg hog</u>
Swine raw waste, Table 25	18
High rate digester-methane generation	18
Composting	14
Lagoon-loading, 1.1 kg COD/week/m ³	13
Solids separation-gravitational devices	10
Oxidation ditch-odor control design	9
Solids separation-size differentiation devices	8
Lagoon-loading, 0.55 kg COD/week/m ³	5-9
Surface aerated lagoons	6
OLF	2-7
Pyrolysis	4.5
Oxidation ditch-nitrogen removal design	3.5
Lagoon-loading, 0.13 kg COD/week/m ³	1.5-3.5
Solids separation-centrifugal force devices	2
Drylot runoff, Table 28	0.9
Drylot runoff retention pond	0.25-0.4
Lagoon-naturally facultative	0.2-0.5
Pasture unit runoff, Table 30	0.09

The economics of these pretreatments may be enhanced by the value of the organic fraction or decreased handling and storage requirements. The cost of such selective and sequential pretreatments is needed to evaluate accurately such pretreatment or conservation approaches. These determinations must be made on a producer basis. A rough cost rating of the most conservative pretreatments would be heavily loaded lagoons, composting, and then high rate digester for methane generation as the most expensive.

When land is not sufficient to receive the total waste nitrogen, then those pretreatment processes which produce the greatest nitrogen removal are most cost-effective. Basically, these are dispersive processes which result in greater than 90 percent nitrogen removal such as drylot production, drylot runoff retention pond, lagoons designed in the range of 0.03-0.06 kg COD/week/m³ of lagoon, and pasture production units, Table 52. Thus, lagoons can be most cost effective for both nitrogen conservation or destruction depending on loading intensity. Nitrogen removal economics must be included with these performance data in order to provide the best total system.

Many of the commonly used pretreatment processes are intermediate with nitrogen removals between 30 percent and 60 percent. The cost of each process divided by the nitrogen removal is a most useful parameter. This cost per unit of nitrogen removed is needed to balance against the value of nitrogen conserved by land application.

Cation or Salt-Based Comparison

The salt content of swine waste may limit land application more than nitrogen in some areas. Salt contents for various pretreatments were limited, so as an approximation the summation of the cations sodium, potassium, calcium, and magnesium was used when possible, Table 53. These elements represent approximately 95 percent of the raw waste cation content and thus were indicative of the relative pretreatment reduction of salts. Basically, the producer objective is to remove cations rather than to conserve them. There is little or no cation removal for most of the studied pretreatments while lagoons provide an intermediate level of about 50 percent reduction. Those units in which swine waste contacts the soil provide the best salt pretreatment c.f. drylot, drylot runoff retention pond, and pasture systems. Although not well documented, extrapolation of removal mechanisms would indicate that overland flow and barred landscape renovation systems would provide substantial salt pretreatment removal.

Table 53. COMPARISON OF PRETREATMENT PROCESSES FOR SWINE WASTE BASED ON REMOVAL EFFICIENCY FOR SALTS

Production unit or pretreatment process	Effluent amount of Na+K+Ca+Mg, g/d/45-kg hog
Swine raw waste, Table 25	21
Oxidation ditch-odor control design	21
Oxidation ditch-nitrogen removal design	21
High rate digestors-methane generation	21
Composting	21
Lagoons 1.1 kg COD/week/m ³	9.2
Lagoons 0.55 kg COD/week/m ³	9.2
Lagoons 0.13 kg COD/week/m ³	9.2
Lagoon naturally facultative	9.2
Surface aerated lagoons	9.2
Drylot runoff, Table 28	1
Drylot runoff retention pond	0.67
Pasture runoff, Table 30	0.10

SECTION VII

SWINE WASTE AND PRETREATMENT RESEARCH NEEDS

In the period 1971-1976, considerable detailed evaluation of waste pretreatment processes has occurred. Much of the data available are sufficient to allow selection of such processes based on the objectives of individual producers. However, for many processes better estimates and more transferability of data is needed for effluent nitrogen and particularly cations or salt content. The pretreatment performance with respect to these two constituent categories should be given research emphasis. The transferability aspect must be addressed by closer reporting and correlation with climatological data.

Specific research needs for the individual pretreatment processes covered in previous sections are found in the performance discussion of these unit processes. With the performance data based on percent removal of LLC the net cost per unit removal of land application limiting constituents must be the next emphasis in the utilization of waste management technology.

The highest current research priority is to determine actual producer costs of available pretreatments and the balance between these and land application.

SECTION VIII

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SECTION IX

PUBLICATIONS ASSOCIATED WITH PROJECT RESULTS

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SECTION X

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